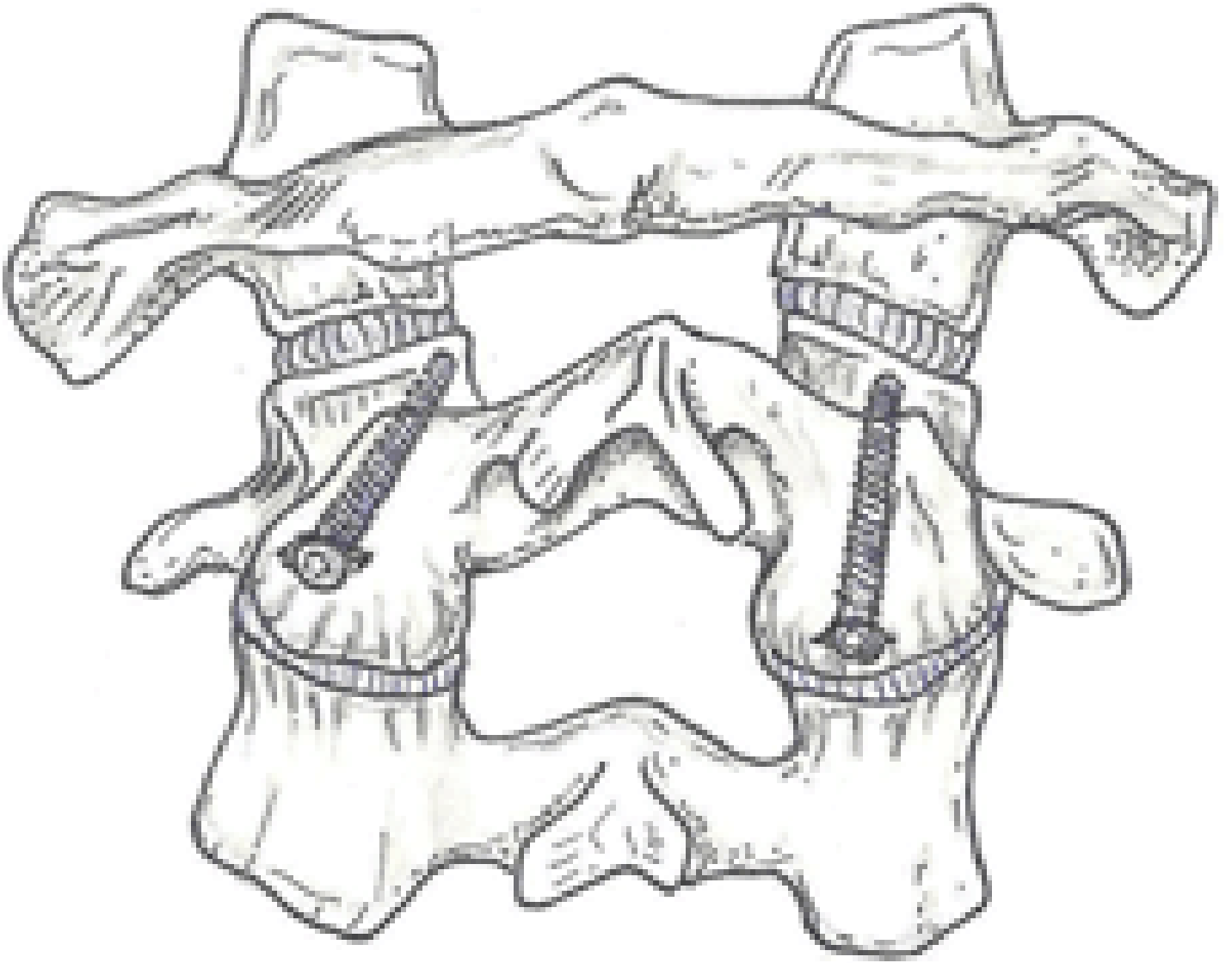


Introduction

Complications of spine surgery

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Over the past 2 decades, we have seen an exponential increase in the number of spine surgeries[3–5] as a result of an expanding elderly population and explosion of technical innovations. During the period from 1990 to 2001, there was a greater than 220% increase in the number of spine fusions performed for degenerative spine diseases.[3] In fact, the rate of spine fusion rose more rapidly in patients older than 60 years than in any other age group,[3,4] with a 15-fold increase in the number of complex spine surgeries for elderly patients with spinal stenosis.[4] Several clinical studies have shown that complications are greater with the increasing complexity of surgery.[1,2,4,6] Studies also revealed that patients over the age of 60 undergoing complex spine surgery are at higher risk for surgical complications.[1,2,6]

Thoughtful consideration of the complications related to spine surgery is essential. Complications lead to longer hospital stay, higher mortality rate, higher readmission rate, and higher overall cost of treatment,[4] all of which lead to diminished efficacy and cost-effectiveness of surgical treatment of degenerative spinal diseases. Although numerous studies have been published on the topic of spine surgery complications in the past, there remains a significant knowledge gap regarding complications related to novel technologies or advanced surgical treatments in the spine that have been developed and gained popularity over the past 2 decades. Critical analysis of past complications can hopefully lead to strategies to avoid future complications and to improve patient outcome.

Despite the inherent difficulty involved in getting surgeons to report or discuss the complications encountered, we received an overwhelming response with more than 50 submissions from contributors throughout the world on this topic. A collection of 20 articles that includes reviews of surgical nuances, original articles, and case reports were selected for the current topic. The articles address issues related to diagnostic considerations, complications related to standard surgical techniques such as pedicle screw instrumentation and anterior lumbar interbody fusion, and complications related to more novel treatments such as minimally invasive spine surgery. We hope that you will find the articles from the current issue to be enlightening as you strive to provide the most optimal treatment outcome for all of your patients. *(DOI: 10.3171/2011.8.FOCUS11204)*

Disclosure

Dr. Hsieh serves as a consultant to Medtronic and DePuy Spine, and has received research support from DePuy Spine. Dr. Gokaslan has direct stock ownership in Spinal Kinetics and US Spine, has received research support from AO North America, Medtronic, and DePuy Spine, and is a paid speaker for the AANS.

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Neurosurg Focus 31 (4):E1, 2011

Diagnostic pitfalls in spine surgery: masqueraders of surgical spine disease

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Disorders of the spine are common in clinical medicine, and spine surgery is being performed with increasing frequency in the US. Although many patients with an established diagnosis of a true surgically treatable lesion are referred to a neurosurgeon, the evaluation of patients with spinal disorders can be complex and fraught with diagnostic pitfalls. While "common conditions are common," astute clinical acumen and vigilance are necessary to identify lesions that masquerade as surgically treatable spine disease that can lead to erroneous diagnosis and treatment. In this review, the authors discuss musculoskeletal, peripheral nerve, metabolic, infectious, inflammatory, and vascular conditions that mimic the syndromes produced by surgical lesions. It is possible that nonsurgical and surgical conditions coexist at times, complicating treatment plans and natural histories. Awareness of these diagnoses can help reduce diagnostic error, thereby avoiding the morbidity and expense associated with an unnecessary operation.
(DOI: 10.3171/2011.7.FOCUS11114)

Key Words • **differential diagnosis** • **medical error** • **nerve compression syndrome** • **nutrition disorder** • **vascular malformations** • **autoimmune diseases of the nervous system** • **infectious disease** • **vasculitis**

Arguably one of the greatest predictors of surgical outcomes in spinal disease is proper patient selection. With the widespread availability of spinal MR imaging and the prevalence of back pain, the presence of disc bulges or protrusions in people with low-back pain may frequently be coincidental.[28] The anatomical continuum that extends from the "normal" asymptomatic spine, to the spine experiencing changes from physiological wear and tear, and to the spine exhibiting degenerative changes responsible for symptomatic disease is a blurred one, creating an abiding debate of what constitutes a pathological, surgically treatable lesion.[29,33,59] Lacking concordance among a patient's history, neurological examination, and neuroimaging studies, spine surgeons can be led astray by incidental radiological findings and can potentially attribute a patient's symptoms to an unrelated entity.[2] Furthermore, surgery may not necessarily alter the natural history of the disease processes, even after addressing an implicated lesion(s).[11,32,71] In addition to all of these difficult aspects of surgical decision making, one must consider the lesions that masquerade as surgically treatable spine disease. Entities less common than a herniated lumbar disc or spinal stenosis do in fact present to spine surgeons. These entities fall outside the spectrum of "indeterminate to definite" surgical utility in the category of "unadvisable." A patient's symptom complexes can be further complicated by the so-called double-diagnostic entities, such as the combination of CTS and cervical radiculopathy—the so-called double-crush syndrome.[67] Because we frequently see patients with these symptoms, accurate diagnosis is necessary to render an excellent surgical evaluation. Conversely, true spinal disease may present to practitioners of different specialties due to the common aspects of presentation.

There are several general categories of diagnostic pitfalls commonly encountered in spinal surgery. The first category involves erroneously attributing a patient's symptoms to an unrelated radiological finding, resulting in an unnecessary operation that fails to address the true cause of the patient's distress; the second category entails the failure to diagnose an unusual presentation of a common spinal disorder; and the third category is the misdiagnosis of something as a surgically treatable spinal disorder that is instead a medical or neurological condition mimicking myelopathy or radiculopathy. In the present review, we provide an overview of some of the common conditions that masquerades as surgically treatable spinal disease.

Abbreviations used in this paper: ALS = amyotrophic lateral sclerosis; CTS = carpal tunnel syndrome; EMG = electromyography; TOS = thoracic outlet syndrome.

* Drs. Walcott and Coumans contributed equally to this work.

Metabolic, Vascular, Inflammatory, and Infectious Masqueraders of Spinal Disease

Metabolic Deficiencies

Malnutrition can be found in all areas of the world and can be the result of deficient nutrient intake, absorption, or utilization. For example, the increasing prevalence of bariatric surgical procedures raises concern for the possibility of increasing prevalence of nutritional deficiencies in this growing population.[57] Micronutrient deficiencies are common in postoperative gastric bypass patients.[60] Hypocupremia, such as found secondary to impaired absorption following bariatric surgery, can mimic significant myelopathy.[10] Spinal cord changes seen in hypocupremia can even affect the brainstem.[34] Supplementation, regardless of the cause, has been effective in correcting the neurological manifestations of copper deficiency.[22,27,35]

Other nutrient and vitamin deficiencies, such as vitamin B12 and folate deficiency, have characteristic effects on the posterior and lateral columns of the spinal cord.[3,53] Symptoms of weakness, paresthesia, impaired proprioception, and impaired vibratory sensation can mimic spinal cord disease, especially severe myelopathy, as the condition progressively worsens. These deficiencies can be secondary to poor absorption and malnutrition in the setting of alcoholism[12,18,69] and pernicious anemia[64] or as a result of impaired cofactor utilization in rare conditions.[55] Micronutrient deficiency should also be addressed in chronic hemodialysis patients with neurological symptoms attributed to the spine because these individuals are commonly deficient of several vitamins and minerals.[30] As homocysteine is converted to methionine en route to myelin synthesis, impairment in this pathway leads to neurological dysfunction and can be corrected with supplementation, not surgery.

In addition to nutritional deficiencies, the chronic condition of impaired glucose utilization (diabetes mellitus) is another widespread disease with secondary neurological effects.[70] Although not yet fully elucidated, our working understanding of the pathophysiology of diabetic neuropathy is that it stems from chronic hyperglycemia, which leads to a dysfunction of primary hemostasis and increased activity of the coagulation system, ultimately reducing endoneurial blood flow. Increased oxidative stresses in turn increase the activity of the nuclear factor–κ B, as well as the production of vasoactive factors and cytokines leading to demyelination and/or programmed cell death (apoptosis).[46,56,76] It is not known why different patients have a predilection for the development of neuropathy in various locations. Diabetic neuropathy that mimics spinal disease can be classified into 3 categories: sensory mononeuropathy, proximal motor neuropathy, and distal sensory neuropathy. An example of sensory mononeuropathy is CTS, a condition that can mimic cervical radiculopathy. Outcomes after surgical release of the carpal tunnel in patients with diabetes indicate that release is an effective treatment.[62] Proximal motor neuropathy can present as weakness, pain, and atrophy of the proximal lower extremities and should not be mistaken for lumbar spinal stenosis.[39] The most common type of neuropathy in diabetic patients, distal sensory neuropathy, typically affects the distal lower extremities first with paresthesia, numbness, or pain. In progressive disease, these symptoms progress proximally and can commonly be confused with or confounded by lumbar spinal stenosis. Because of diabetes' widespread prevalence, it is important to determine preoperatively if this disease is present. In addition to establishing a differential diagnosis of surgically and nonsurgically treatable spinal conditions, it is also useful in the surgical evaluation of patients. In the Spine Patient Outcomes Research Trial, diabetic patients with spinal stenosis and degenerative spondylolisthesis were shown to benefit from surgery, whereas patients with disc herniations and diabetes generally did not benefit from surgical intervention.[20] Hence, even traditionally viewed surgically treatable lesions in diabetic patients may in fact be masqueraders of surgically correctable lesions.

Infectious Diseases

Infection of the spine can be classified as intradural infectious disease, extradural infectious disease, and vertebral column infectious disease. The first and last of these are generally treated nonsurgically, whereas the second often represents a surgical emergency. (A caveat to this would be the rare case of subdural empyema.) Intradural infectious disease can produce symptoms attributable to a mass lesion within the spinal cord itself or even mimic radiculopathy. Infections, such as tuberculosis, have been reported to infiltrate the spinal cord and are treated effectively with antitubercular agents.[51,52] Although tuberculosis is more common in developing countries, immunocompromised patients in any geographic location should raise suspicion for infectious conditions. In a review of 55 patients with AIDS and associated spinal infections or neoplasms, cytomegalovirus polyradiculitis was the most common cause of intradural extramedullary disease, with herpes radiculitis and tuberculous infection being less common.[63] HIV itself can cause direct infiltration of the spinal cord, resulting in a condition known as vacuolar myelopathy.[49] Spirochete infection can also infiltrate the spinal cord and cause inflammation associated with neurological manifestations.[1] The mainstay of these treatments is nonsurgical.

Infectious disease of the disc space and vertebral body are causes of severe back pain and can mimic surgical causes of radiculopathy, myelopathy, and sensory loss. Unlike the disc space, excellent clinical outcomes are typically achieved nonsurgically when the structural integrity of the vertebral body is maintained. Risk factors for osteomyelitis of the spine include immunocompromised status, intravenous drug abuse, and the presence of a right-to-left cardiac shunt.[4]

Autoimmune, Neurodegenerative, and Inflammatory Disease

Imaging and pathomorphological studies in multiple sclerosis suggest that axonal injury and axonal loss play a crucial role in individuals with persistent disability and long-standing disease.[38] Demyelinating plaques and myelitis, particularly in the cervical spinal cord, can produce a variety of neurological conditions that are shared with surgical spine lesions. These include weakness, radiculopathy, and myelopathy.[43,48]

Other examples of diseases with insidious onset that commonly present for spine surgery evaluation include ALS and Parkinson disease. In a study of 344 patients with Parkinson disease, 6% were initially referred to a surgeon for spinal or gait-related problems.[72] Also, early ALS can mimic radiculopathy, myelopathy, mononeuropathy, and arthropathy. In a review of 260 consecutive patients with ALS, 55 had had surgery within the 5 years prior to diagnosis of ALS. A remarkable 34 of these 55 underwent surgery for symptoms and signs that retrospectively were attributable to early manifestations of ALS.[61]

Clinical Vignette: Case 1

This 63-year-old man presented to our clinic with neurological decline following anterior cervical discectomy and fusion for cervical myelopathy. He had developed worsening gait unsteadiness, spasticity, and hand clumsiness (Fig. 1). He underwent posterior laminectomy, and his symptoms initially improved. Three years later, however, he began ambulating slower, taking short steps, and he had a stooped posture. Consideration was given to possible decompression of adjacent levels that were stenotic (Fig. 2). On examination, he had now developed increasing left-sided stiffness with spasticity and a new left-sided tremor. He was referred to a movement disorder neurologist who diagnosed Parkinson disease. Neurological symptoms were treated successfully with dopamine agonist therapy; further surgery was avoided.

Clinical Vignette: Case 2

This 63-year-old woman presented with progressive, painless bilateral arm weakness. The weakness was greater on the right side and affected the proximal muscles more prominently (deltoid muscle Grade 3/5 strength; remaining muscle groups Grade 4/5 strength). Magnetic resonance imaging demonstrated a prominent C6–7 disc resulting in severe stenosis at that level (Fig. 3). The patient's neurological findings did not correlate with the imaging findings, and electromyography demonstrated positive sharp waves, fibrillations, and long-duration and high-amplitude motor unit action potentials throughout right arm, right thoracic paraspinal areas, and right leg, consistent with the electrodiagnostic criteria for ALS.[15] Surgery was averted as her symptoms were not attributable to the radiographic lesion and could be explained by her systemic diagnosis.

A variety of other systemic inflammatory diseases such as Behçet disease and sarcoidosis can also mimic disease of the spine treated surgically. While uncommon, they must be recognized as nonsurgical entities.[29,75] In fact, in a study of patients treated for spinal cord sarcoidosis, the nonsurgical group had better outcomes than the surgical group.[23]

Clinical Vignette: Case 3

This 37-year-old man presented with axial cervical and thoracic spine pain. There were no neurological findings such as weakness or abnormal reflexes. Flexion and extension of his neck was limited secondary to pain. There was no lymphadenopathy, and his serum laboratory studies were normal except for an elevated serum angiotensin-converting enzyme level. Plain chest radiography and abdominal CT scanning showed findings within normal limits. Spinal MR imaging demonstrated several cervical, thoracic, and lumbar vertebral bodies with abnormal, increased signal intensity (Fig. 4). Biopsy of a skin rash demonstrated sarcoidosis. After 6 months of steroid therapy, all the patient's symptoms resolved, and repeat MR imaging revealed normal finding (Fig. 5).

More localized inflammatory conditions can also mimic disorders of the spine that are amenable to surgery, such as brachial neuritis (Parsonage-Turner syndrome).[44] Patients with this condition often experience a sudden onset of severe pain in or about the shoulder girdle, followed by weakness of at least one shoulder muscle.[66] This can

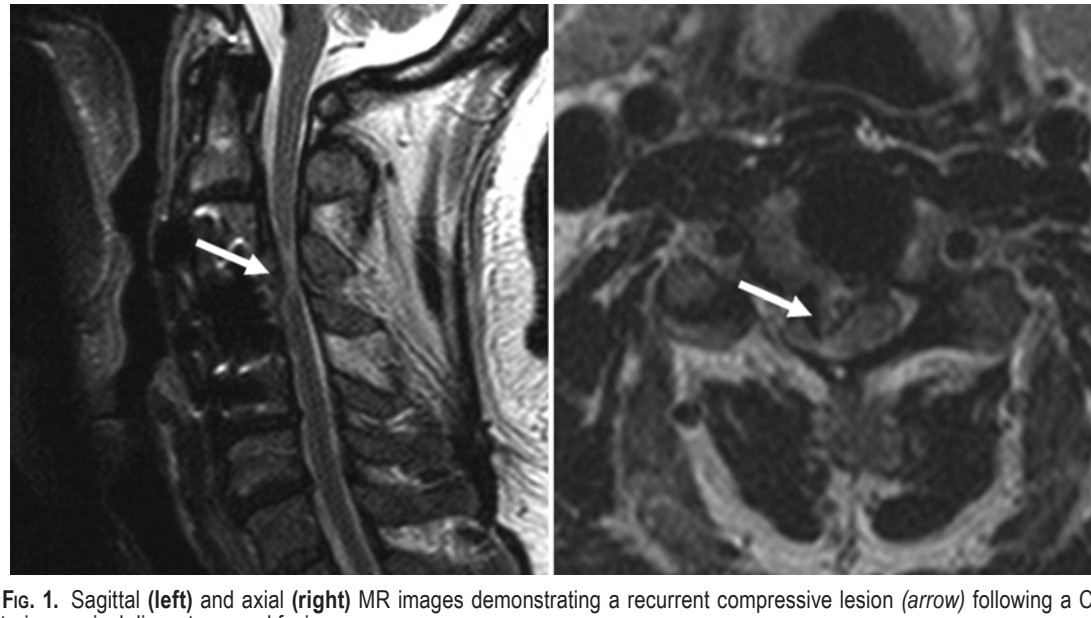


Fig. 1. Sagittal **(left)** and axial **(right)** MR images demonstrating a recurrent compressive lesion *(arrow)* following a C3–5 anterior cervical discectomy and fusion.



Fig. 2. Sagittal MR image revealing postlaminectomy changes. Note the persistent stenosis at the C2–3 level.

easily be confused with a number of disorders, such as cervical radiculopathy (particularly in patients with significant preexisting spondylosis). The diagnosis should be suspected, especially when the pain decreases spontaneously and weakness subsequently develops. Electromyography can confirm the neuropathy once weakness is apparent.

Peripheral Vascular Disease

The differentiation of neurogenic claudication (resulting from lumbar spinal stenosis) from lower-extremity vascular claudication is not always easy from a patient's history of lower-extremity cramping on exertion.[25,42] Peripheral arterial disease is typically also associated with impotence in men, dystrophic skin changes, foot pallor, and decreased peripheral pulses. Typically, patients with neurogenic claudication experience relief with changes in posture (bending forward, sitting, and so on) as opposed to vascular claudication that merely improves with rest regardless of position. Ankle/brachial indices, Doppler ultrasound, and vascular surgery consultation may be helpful in suspected cases.[24,54] Electromyography may also be helpful in reaching a diagnosis.[17] Ultimately, like several of the conditions described in this review, these conditions may occasionally coexist in the same patient.



Fig. 3. Sagittal MR image showing a herniated C6–7 disc. The level of compression did not correlate with findings on the patient's neurological examination.

Inherited Neurological Diseases

Certain inherited neurological diseases have variable penetrance and delayed onset of expression. Thorough assessment must be undertaken to identify discrepancies in a patient's history and examination, particularly when radiographic and physical findings are discordant.

Clinical Vignette: Case 4

This 44-year-old man presented with upper- and

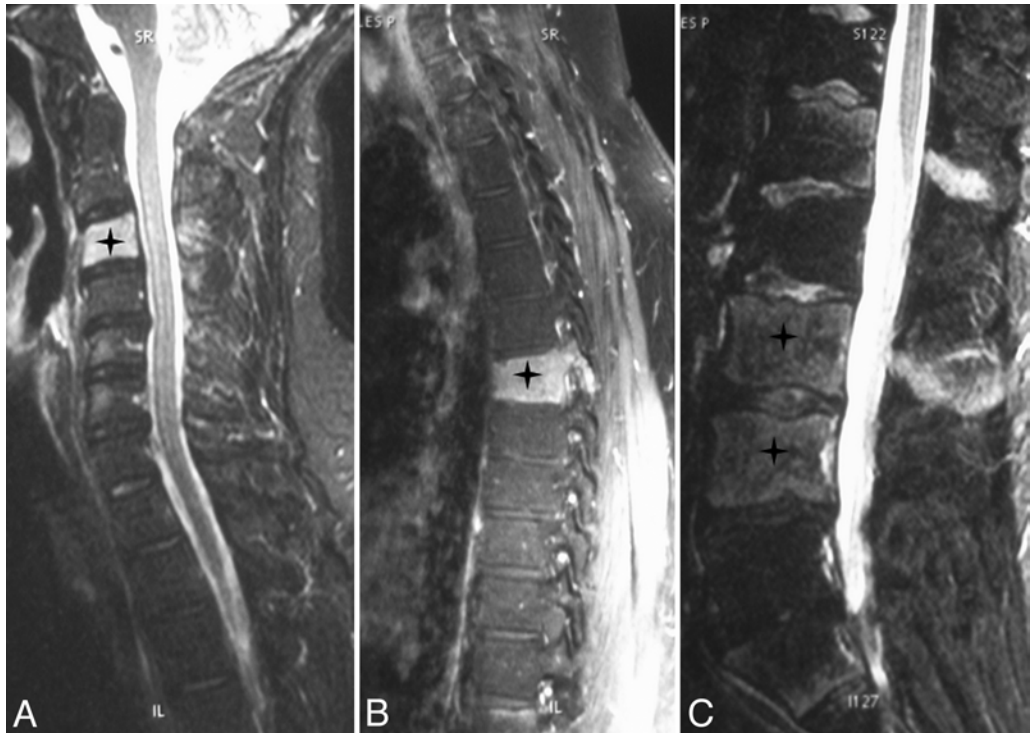


Fig. 4. Sagittal MR images of the cervical **(A)**, thoracic **(B)**, and lumbar **(C)** spine demonstrating vertebral bodies with abnormal, increased signal intensity *(star)*.

lower-extremity weakness and muscular atrophy. He was found to have multilevel cervical stenosis and elected to undergo multilevel cervical laminectomy and foraminotomy. Postoperatively, he experienced continued loss of function, despite adequate radiographically documented decompression. Profound atrophy of the right trapezius, supraspinatus, infraspinatus, deltoid, and biceps muscles was present (Fig. 6). While there was initially concern for residual cervical root compression, further workup revealed spinal muscular atrophy Type IV. Further surgery was not indicated as a causative diagnosis had been reached.

Musculoskeletal Masqueraders of Surgical Spinal Disease

Because upper- and lower-extremity musculoskeletal problems are common, the spine surgeon must frequently evaluate a patient who has both a spinal condition and an appendicular source of pain. In a review of patients referred for electrodiagnostic testing, for example, 21% of the patients with a lumbosacral radiculopathy also had a musculoskeletal disorder such as myofascial pain, trochanteric bursitis, or iliotibial band syndrome.[8]

Shoulder Pathology

Patients with shoulder disease can present with pain and weakness, and this pathological entity needs to be differentiated from cervical radiculopathy. Occasionally, a patient with a rotator cuff tear undergoes MR imaging of the cervical spine and is referred for nerve root decompression, usually the C-5 nerve. Attention to the possibility of shoulder pathology in the examination of a patient with suspected C-5 nerve dysfunction could avoid a diagnostic error. In C-5 radiculopathy, there can be weakness of shoulder abduction, flexion, internal and external rotation, and elbow flexion. The pain is often provoked by movement of the neck, and it radiates form the neck down. The pectoral and the biceps reflexes are affected. There can be decreased range of motion of the shoulder due to weakness, but the movement is generally not painful unlike what patients can experience with rotator cuff tears. With rotator cuff tears, activity often produces pain that is diffuse and can resemble C-5 radiculopathy (especially when performing overhead movements). Rotator cuff tears produce weakness of shoulder abduction and external rotation. When a tear has been present chronically, it is associated with atrophy of the supra- and infraspinatus musculature. If a rotator cuff tears is suspected, an MR image of the shoulder should be obtained, as the modality is both sensitive and specific.[6] A shoulder examination, including palpation, range of motion, strength testing, and provocative tests, is usually diagnostic, and its effectiveness has been reviewed recently.[6] Electromyography and selective nerve root blocks can be used for further diagnostic elucidation.[40]

Another shoulder condition, acromioclavicular arthritis, often presents with localized pain over the anterosuperior aspect of the shoulder and tenderness and is uncommonly mistaken for cervical radiculopathy. The cross body adduction test is frequently positive in acromioclavicular arthritis. Additionally, adhesive capsulitis often presents with pain and a reduction of range of motion. The pain is often diffuse, can encompass the deltoid re-



Fig. 5. Sagittal MR image of the cervical spine following 6 months of steroid therapy. This segment, as well the thoracic and lumbar regions (not pictured), appeared normal.

gion, and can resemble a C-5 radiculopathy. Radiographic studies are generally negative. Passive range of motion is significantly limited, unlike that in a patient with radiculopathy. A diagnosis is more complicated if both spine and shoulder conditions are present.

Clinical Vignette: Case 5

This 78-year-old man, with a known supraspinatus tear and shoulder pain, presented with progressive weakness of external shoulder rotation. His internist suspected a superimposed radiculopathy, and cervical imaging demonstrating severe C-4 and C-5 foraminal stenosis (Fig. 7); EMG revealed evidence of an ipsilateral C-5 radiculopathy. He was appropriately referred for surgical decompression and improved following selective foraminotomy.



Fig. 6. Photographs showing profound atrophy of the right trapezius, supraspinatus, infraspinatus *(arrow)*, deltoid, and biceps muscles in a patient being evaluated for recurrent cervical stenosis. Note the midline, posterior cervical scar from his previous cervical laminectomy and foraminotomy.

Tendon Rupture

The diagnosis of a biceps tendon rupture is generally straightforward. It presents with weakness, pain and tenderness, and a deformity of the muscle. Triceps tendon rupture, however, is rare.[68] It occurs most commonly as a result of a fall on outstretched arms or, more rarely, as a result of trauma to the back of the arms. It presents with triceps weakness, tenderness, and, if the diagnosis is delayed, a decrease in the range of motion. In nearly half the patients in the largest series, there was an error in the initial diagnosis.[68] A diagnostic delay often precludes a primary repair, complicating the surgery and the recovery. Due to the rarity of this disorder, it can be mistaken for a C-7 radiculopathy.

Clinical Vignette: Case 6

This 66-year-old man had previously underwent a cervical laminoplasty for cervical stenosis. He presented with the new-onset bilateral triceps weakness after a mechanical fall. Cervical MR imaging demonstrated residual stenosis of the C-7 nerve roots. He was referred by a neurologist for consideration of reoperative decompression. Physical examination revealed features consistent with bilateral triceps tendon rupture, and the patient underwent bilateral repair with improved strength postoperatively. Spinal reoperation was not necessary.

The diagnostic features distinguishing triceps tendon rupture from a cervical radiculopathy are based on the physical examination. They include the presence of tenderness at the site of possible rupture, a palpable defect in the tendon, and the absence of weakness in other C-7 myotomes, such as the wrist and finger extensors.[68]

Hip Arthropathy

Patients with hip pathology can present with symptoms that mimic spinal stenosis or lumbar radiculopathy. Hip and spine degenerative disease are common, and their incidence increases with advancing age. It is therefore not surprising to encounter each condition in the same patient. A comprehensive review of the incidence

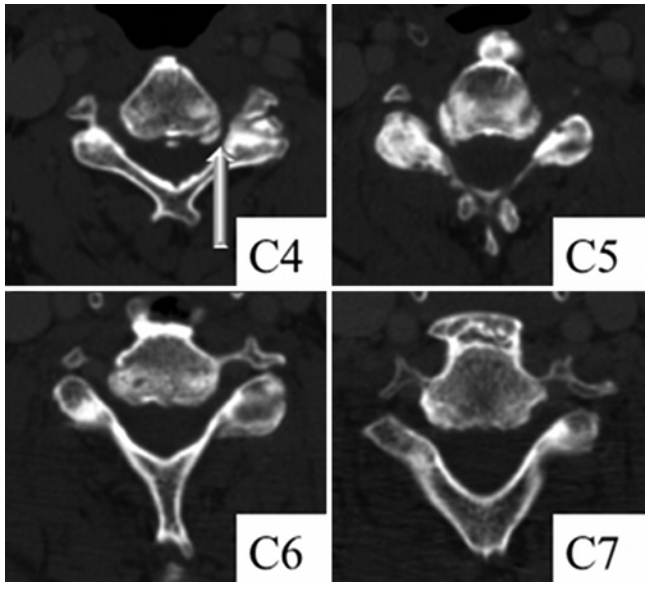


Fig. 7. Axial CT scans of the cervical spine demonstrating severe left C4–5 stenosis *(arrow)*, implicated in the compression of the left C-5 nerve root.

of hip osteoarthritis places the mean incidence at 8%.[13] Lumbar stenosis studies place its prevalence higher than 19% in individuals over 60 years of age.[31]

Patients with hip arthritis present with pain in the inguinal region, an antalgic gait, and a decreased hip range of motion. The groin pain can radiate widely and commonly affects the anterior and lateral thigh. It can also involve the buttock and can occasionly radiate below the knee.[13] A study of referred pain patterns in patients undergoing hip intraarticular injections demonstrated that the buttock was a site of referral in 71% of patients compared with the thigh (57%) and the groin (55%).[36] An upper lumbar radiculopathy can also cause radiating pain to the inguinal region and anterior thigh. Usually, a careful examination can clarify the diagnosis. The absence of a sensory disturbance, the provocation of pain on internal rotation of the hip joint, and an antalgic gait with an abbreviated strike phase on the affected side should alert one to the presence of a hip problem. In fact, a retrospective study of patients presenting to an orthopedic clinic found that patients with a limp and limited internal rotation of the hip were 7 times more likely to have a hip problem than a spinal diagnosis.[5] In another study of patients presenting to a spine clinic, 12.5% of patient had a diagnosis referable to a hip joint.[58] Plain radiographs of the hip are readily obtainable and can reveal a decreased joint space, the presence of subchondral cysts, sclerosis, and the formation of osteophytes.[13]

Occasionally a double diagnosis exists with a single pain being dominant. In this situation, it is advisable to discuss with the patient which symptoms are attributable to each region and to decide whether an operation at one or both sites is warranted.

Clinical Vignette: Case 7

This 41-year-old man had symptoms of neurogenic claudication and right thigh pain when ambulating. He was referred for a lumbar laminectomy by a neurologist after an MR imaging revealed L3–4 and L4–5 central canal stenosis. His neurological examination was unrevealing. Physical examination demonstrated a markedly reduced and painful range of motion of the right hip. He ambulated with a limp. Plain radiography and MR imaging (Fig. 8) confirmed the diagnosis of hip arthropathy, and the patient elected to undergo a hip replacement and a lumbar decompression because he had symptoms attributable to both areas. Postoperatively, he experienced resolution of both the stenosis and hip-related symptoms.

Peripheral Nerve Diseases and Entrapment Masquerading as Compressive Radiculopathy

Patients with entrapment neuropathies can present with weakness, pain, and sensory loss. When they occur in a patient with concurrent spondylosis or stenosis, they can lead to an unnecessary spinal operation. In general, the key to the diagnosis is in the characterization of factors that exacerbate the symptoms and in the distribution of the sensory and/or motor abnormality.

Thoracic Outlet Syndrome Mimicking Cervical Radiculopathy

Thoracic outlet syndrome can present with symptoms resembling cervical radiculopathy. It can be divided into neurogenic TOS, vascular TOS, and disputed TOS.[26] Vascular TOS occurs less commonly than neurogenic TOS and presents with venous stasis, arterial insufficiency, and even embolic stroke. It is not typically diagnostically confused with cervical radiculopathy. Neurogenic TOS, however, generally presents with an inferior brachial plexus compression. As it courses to the arm, the plexus travers-

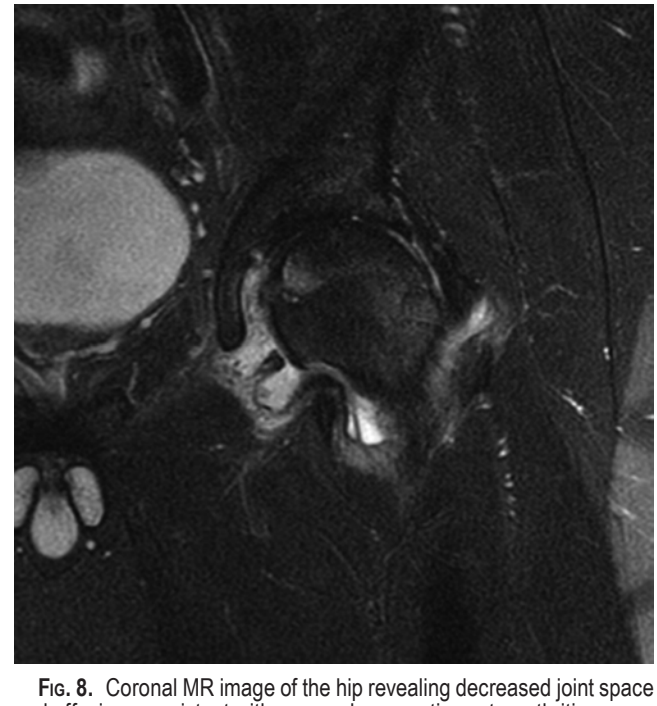


Fig. 8. Coronal MR image of the hip revealing decreased joint space and effusion, consistent with severe degenerative osteoarthritis.

es 3 potential sites of impingement. The most common is the interscalene triangle, but it can also occur in the costoclavicular space and the retropectoralis minor space or subcoracoid space.[16] It is more common in females and in individuals with a slender neck and drooping shoulders. It can be caused by an anomalous fibrous band originating from an elongated C-6 or C-7 transverse process and inserting into the first rib or lung cupola. Less commonly, it is related to a cervical rib that may be rudimentary or complete.[45] These anatomical abnormalities cause compression of the lower trunk of the brachial plexus. Pathological studies of cadaveric specimens with a cervical rib have demonstrated changes within the nerves at the site of contact as well as distally.[65] The authors did not find similar changes in control specimens. Patients with this entrapment syndrome present with weakness of the abductor pollicis brevis, interosseus, and hypothenar muscles with ulnar distribution sensory involvement.[26]

The most important differential diagnosis in a patient with suspected TOS is that of cervical radiculomyelopathy. It has been pointed out that TOS is likely underdiagnosed. In a series of patients ultimately diagnosed with this condition, some had previously undergone unsuccessful cervical decompression.[45] Patients with TOS may undergo cervical imaging and can be referred to a surgeon for decompression of a C-8 or T-1 nerve root.

Unfortunately, there are no reliable physical examination tests for TOS. In a study of diagnostic tests performed by a blind examiner in healthy individuals and patients with CTS, a high false-positive rate was observed, especially in patients with CTS.[47] Cervical and chest radiography can reveal a cervical rib or an elongated transverse process.[16] Electrodiagnostic studies can be helpful and the TOS findings have been summarized.[26] There is a disconnect between sensory and motor findings of the ulnar and median nerves, with a decrease in the amplitude of ulnar sensory action potentials and in median compound motor action potentials. In contrast, the ulnar motor potentials and the median nerve sensory potentials are normal. This has been explained by the fact that the C-8 and T-1 fibers travel in the ulnar nerve and not in the median nerve. Motor fibers originating from the C-8 and T-1 roots travel in both the median and ulnar nerves, but the ones destined for the median nerve are disproportionately affected.[26]

Suprascapular Nerve Entrapment Mimicking C-5 or C-6 Radiculopathy

The suprascapular nerve is a branch of the upper trunk of the brachial plexus. It supplies motor fibers to the supraspinatus and infraspinatus muscles, and receives sensory input from the glenohumeral and acromioclavicular joints. Entrapment is rare and can be the result of a ganglion from the glenohumeral joint or compression at the suprascapular notch.[74] It presents with pain in the region of the scapula that can radiate down the arm and can resemble the symptoms seen with either shoulder pathology or cervical radiculopathy. There is usually no history of trauma.[74] Because of its rarity, the time to diagnosis is prolonged, leading to weakness of external rotation and abduction of the shoulder, as well as atrophy of either the infraspinatus muscle or both the supraspinatus and infraspinatus muscles. Diagnostic errors are common, and patients with this syndrome have mistakenly undergone surgery for cervical radiculopathy.[50] In patients with concurrent cervical spondylosis, suprascapular nerve entrapment can be differentiated from a C-5 radiculopathy by the absence of a Spurling sign and lack of reproduction of the pain with neck movement. Additionally, there should be an absence of weakness beyond the shoulder abductor and external rotator and an absence of a sensory component or reflex abnormality in an entrapment syndrome. On EMG testing, patients with suprascapular nerve entrapment exhibit denervation in the supraspinatus and or infraspinatus muscle, with sparing of other C-5–innervated muscles such as the deltoid and biceps. If it is caused by a ganglion cyst, ultrasound or an MR imaging will demonstrate the cyst. However, in cases of impingement at the level of the transverse ligament, imaging will typically be negative.[21]

Axillary Nerve Entrapment Mimicking C-5 Radiculopathy

The axillary nerve emerges from the posterior cord of the brachial plexus and traverses the quadrilateral space before giving rise to the teres minor and deltoid nerves. It traverses the quadrilateral space with the posterior circumflex humeral artery. Entrapment of the axillary nerve in the quadrilateral space was first described in 1983.[7] It usually occurs spontaneously in young individuals. It presents with pain over the quadrilateral space, anterior aspect of the shoulder, and arm paresthesias. The presentation resembles rotator cuff tendinitis, acromioclavicular pathology, and C-5 radiculopathy. It is a rare entrapment and is therefore likely underdiagnosed.[9] The results of neurological examination are often normal, although there may be deltoid weakness. Magnetic resonance imaging can reveal atrophy of the teres minor.[37] Electrodiagnostic testing can demonstrate deltoid denervation.[19] If positive, the EMG findings narrow the diagnosis because the observed denervation is limited to the deltoid muscle. In contrast, C-5 radiculopathy is also associated with denervation of the paraspinal musculature, the supraspinatus, and the biceps musculature. Angiography can demonstrate occlusion of the posterior circumflex humeral artery with abduction and external rotation of the arm.[9]

Carpal Tunnel Syndrome Mimicking C-6 Radiculopathy

Cervical radiculopathy and CTS are both common and can coexist in the same patient. In a series of 12 patients who initially were diagnosed with CTS and who underwent ineffective operations, 3 were ultimately diagnosed with cervical radiculopathy.[73] The prevalence of CTS is approximately 125 per 100,000.[14] Patients with CTS present with hand numbness, paraesthesias, and pain that can radiate into the forearm and, rarely, into the arm. Although patients frequently describe the symptoms as affecting the entire palm of the hand, the distribution of sensory symptoms most closely resembles the C-6 dermatome.

There are a number of key distinguishing features between CTS and cervical radiculopathy. The symptoms of CTS are often worse after use of the hand and at night. Although the pain and paresthesias can radiate up the

forearm and arm, there is a sensation that they originate in the palmar region of the hand. The symptoms of cervical radiculopathy, unlike those of CTS, can often be provoked by neck movement. A careful sensory examination can differentiate the 2 conditions. In CTS, inspection of the musculature may reveal an asymmetry in the thenar eminence. Any loss of motor dysfunction is limited to the thenar muscles. In a C-6 radiculopathy, the biceps, triceps, wrist flexors, and deep finger flexors can all be affected. In CTS, the loss of sensation occurs distal to the wrist crease and spares the proximal palmar aspect of the hand, due to the forearm takeoff point of the palmar sensory nerve. In a cervical radiculopathy, the loss of sensation can be pronounced at the level of the fingers because of their rich innervation, but it extends into the forearm.

Ulnar Nerve Entrapment at the Elbow Mimicking C-8 Radiculopathy

This is not a common diagnostic pitfall because the 2 conditions present differently. In general, C-8 radiculopathy is uncommon. The key to distinguishing these 2 entities is a careful examination. Percussion of the ulnar nerve at the elbow often elicits a Tinel sign. Keeping the elbow flexed for 3 minutes often provokes the symptoms. In severe C-8 radiculopathy, there is weakness of thenar muscles, which are carried with the median nerve and are therefore spared in severe ulnar neuropathy. In ulnar nerve entrapment at the elbow, the sensory examination is characterized by hypesthesia over the fourth and fifth digits, extending over the palm and dorsal aspect of the hand medially. In C-8 radiculopathy, the sensory loss extends proximally over the medial forearm.

Peroneal Nerve Palsy Mimicking L-5 Radiculopathy

An L-4 or L-5 radiculopathy can result in weakness of ankle dorsiflexion. At times a patient with a foot drop may be referred for foraminal decompression when, in fact, the problem is peripheral. Lumbosacral plexopathies, sciatic neuropathies, and peroneal nerve palsies can all present with weakness of ankle dorsiflexion and a steppage gait.[41] Because the peroneal nerve arises from fibers of the L-4, L-5, and S-1 nerve roots, radiculopathy affecting these roots necessarily also affects the peroneal nerve. There are a number of important differences on motor and sensory examination. As with any attempt at differentiating potential nerve root pathology from a peripheral nerve entrapment, one must attempt to identify a muscle both supplied by the suspected root and uninvolved with a potential entrapment. In peroneal nerve palsy, the motor weakness involves the ankle and toe dorsiflexors and the ankle evertor muscles. In L-5 radiculopathy, there is weakness of ankle inversion (tibialis posterior muscle), which is carried by the posterior tibial nerve, in addition to the weakness of dorsiflexion and toe extension. An L-4 radiculopathy presents not only with dorsiflexor and inversion weakness, but commonly there is also frequent weakness of the quadriceps muscle and a diminished patellar reflex. On sensory testing, differences can also be characterized. In peroneal nerve palsy, the sensory abnormality can limit itself to the first web space if it involves only the deep branch of the peroneal nerve. If the entrapment affects both the deep and superficial peroneal nerves, the sensory abnormality will also involve the top of the foot and lateral aspect of the leg but will not be as proximal in extent as an L-5 radiculopathy.

Conclusions

Meticulous evaluation is necessary to identify lesions that masquerade as surgically treatable spine disease that can lead to erroneous diagnosis and treatment. Key aspects of the historical presentation, diagnostic and provocative examination of the patient, and anatomical understanding should be considered of primary importance in the evaluation of select patients given the high prevalence rates of radiographically documented spinal abnormalities.

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: Coumans. Drafting the article: all authors. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Walcott.

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Manuscript submitted May 23, 2011.
Accepted July 28, 2011.

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Neurosurg Focus 31 (4):E2, 2011

Complication management with minimally invasive spine procedures

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Spine surgery as we know it has changed dramatically over the past 2 decades. More patients are undergoing minimally invasive procedures. Surgeons are becoming more comfortable with these procedures, and changes in technology have led to several new approaches and products to make surgery safer for patients and improve patient outcomes. As more patients undergo minimally invasive spine surgery, more long-term outcome and complications data have been collected. The authors describe the common complications associated with these minimally invasive surgical procedures and delineate management options for the spine surgeon. *(DOI: 10.3171/2011.8.FOCUS11165)*

Key Words • **minimally invasive** • **spine surgery** • **complications**

With recent advances in technique and access instrumentation, minimally invasive spine surgery has ushered in a renaissance in spine care. Surgeons are becoming more comfortable with these procedures, and industry-surgeon collaborations have provided a plethora of new products to make surgery safer for patients and improve patient outcomes. As more patients receive minimally invasive spine surgery treatments, stronger long-term outcome data are supporting this change in practice pattern.[20,21] Patient outcomes are improved compared with traditional open surgery and costs are reduced, partly due to reduced hospital stays and recovery times. Approach-related morbidity is significantly reduced because normal anatomical structures are preserved to a greater extent, reducing the incidence of delayed progressive deformity and degenerative changes. Minimally invasive surgical procedures of the spine can be just as efficacious as traditional open procedures with respect to the operative pathology. Unnecessary approach dissection and ligamentous and muscular disruption are minimized, potentially leading to a reduced incidence of repeated operations and scar formation.

However, minimally invasive surgical procedures require specialized surgeon training and offer many new technical challenges. Adequate training and familiarity with the microsurgical anatomy through retractor ports, coupled with the appropriate level of surgeon skill and manual dexterity, are critical for procedural success. Training courses, specialized fellowship training, animal and cadaveric dissections, and technique guides are all available to help educate surgeons, improve patient outcomes, and reduce complications.

Endoscopic optics, although improving, can limit 3D image representation and provide imperfect color representation. Tissues of similar color and structure are difficult to differentiate, such as nerve roots and the ligamentum flavum. Surgeons mistaking these structures could encounter intraoperative complications such as dural tears or nerve root injury. Recent developments in tubular retractors, which can reduce the need for thoracoscope or endoscope use, permit 3D visualization through loupe magnification and/or the operating microscope. However, these ports expose only a small portion of the spine and relevant anatomy; therefore, surgeons must have a clear understanding of the surrounding anatomy and possible complications that can occur with each approach. Understanding and thus avoiding possible complications are critical in making minimally invasive spine surgery safe and effective.

Cervical Procedures

Anterior Cervical Discectomy and Fusion

Anterior cervical discectomy and fusion is one of the most common spinal surgical procedures. It has a low complication and morbidity rate. First introduced in the 1950s by Cloward,[8] the cervical vertebral bodies are approached through the standard fascial approach medial to the sternocleidomastoid muscle. In a recent series of 1015 patients undergoing anterior cervical discectomy and fu-

Abbreviations used in this paper: AANS = American Association of Neurological Surgeons; CNS = Congress of Neurological Surgeons.

sion,[11] the most common complication was dysphagia, which occurred in 9.5% of patients. Postoperative hematoma occurred in 5.6%, and required surgical intervention in 2.4%. Symptomatic recurrent laryngeal nerve palsy occurred in 3.1% of cases, while dural tear was observed in 0.5%. Improvements in cervical retractor design (thinner blades) can potentially reduce postoperative dysphagia. In addition, no- or zero-profile interbody implants made of polyetheretherketone (PEEK) and typically anchored with screws placed through the implant and into the adjacent vertebral body can potentially reduce dysphagia, although clinical data to support this idea are lacking. Laryngeal nerve injury with hoarseness usually resolves after a few days. If hoarseness persists for more than 4 weeks, laryngoscopy should be undertaken to evaluate vocal cord function. Electromyographic, somatosensory, and motor evoked potential monitoring during these procedures can help identify positioning and intraoperative changes. However, it remains controversial as to whether intraoperative monitoring can result in improved patient outcomes (Hussain NS, Rosenblum AR, Kudrimoti HS: Analysis of 1014 consecutive operative cases to determine the utility of intraoperative neurophysiological data. Paper presented at the AANS Annual Meeting, Denver, Colorado, April 9–14, 2011).[6,22]

Possible complications that require immediate intraoperative treatment include laceration of the larynx or esophagus. These injuries, if identified immediately, should be closed primarily, followed by wound drainage and nasogastric tube drainage. The patient should then receive a formal swallowing study before discharge and 4 weeks postoperatively to assess for proper closure and function of the esophagus and to rule out aspiration. Misplacement of the retractor may result in carotid artery injury, which should be repaired. Internal jugular vein injury should be managed with primary repair or ligation. Again, as is the case for other procedures, adequate training under experienced surgeons, cadaveric and animal courses, and a 3D "see-through" knowledge of the surrounding anatomy and critical structures are all key to reducing complication risk.

Anterior Cervical Foraminotomy

Initially described by Verbiest[25] in the 1960s, anterior cervical foraminotomy has been advocated for unilateral radicular symptoms due to foraminal stenosis from lateralized disc herniation. The benefits of this approach are that a fusion is avoided, thus preserving the motion segment. The disadvantage is that the approach is not familiar to most surgeons and the proximity of the vertebral artery puts it at risk for injury. Jho[14] has comprehensively described the primary risk of vertebral artery injury with this procedure. He reported the 3 most likely sites of injury to be at C6–7, in the region lateral to the uncinate process, and at the foramen transversarium. The C6–7 level is a high risk because of the local anatomy. The vertebral artery courses between the transverse process of C-7 and the longus colli muscle. Jho recommends that surgeons incise the longus colli muscle at the level of the C-6 transverse process to avoid vertebral artery injury. The cut muscle stump is then reflected caudally over the C-7 transverse process, exposing the vertebral artery. At the uncinate process, vertebral artery injury can be avoided by drilling down the uncovertebral joint and leaving a thin layer of cortical bone over the vertebral artery. This thin bone can then be removed with a curette. Brisk venous bleeding during drilling can indicate breach of the surrounding venous plexus that surrounds the vertebral artery.

Vertebral artery injury is difficult to repair primarily. Most surgeons will pack the region with Gelfoam, muscle, or bone wax and evaluate using postoperative angiography. Injury to the sympathetic chain, resulting in Horner syndrome, is another risk with this approach for surgery. The cervical sympathetic chain lies anterior to the longus colli muscle. Careful retraction of the longus colli muscle laterally and avoiding any muscle resection can reduce the rate of injury to this structure. Poor patient selection can also lead to poor outcomes. Patients with mechanical neck pain, who would have a better outcome with a fusion procedure, often do not improve with decompressive procedures. Performing the foraminotomy at junctional levels may result in worsening spinal biomechanics with worsening pain due to partial uncovertebral joint removal. In addition, some patients who develop contralateral foraminal narrowing may develop symptoms from this narrowing due to hypermobility induced with the foraminotomy.

Posterior Cervical Foraminotomy

A muscle-splitting approach using sequential tubular muscle dilators has proven to be effective in limiting postoperative pain and spasms when performing posterior cervical procedures. This approach allows this procedure to be performed on an outpatient basis. The posterior foraminotomy maintains the midlines osseous, muscular, and ligamentous structures of the spine. With this type of surgery, prone positioning inherently places pressure on the face. Pressure over the eyes can potentially cause hypoperfusion in the distribution of the central retinal artery, resulting in infarction and vision loss. This may be avoided by using a Mayfield head holder or appropriate padding of all pressure points. Alternatively, the patient can be put in a semisitting position with the head affixed in a Mayfield head holder. This positioning also allows for blood to move out of the tube and not obscure the surgical field of view. Spinal cord injury can occur while docking the K-wire and/or serial muscle dilators, which is a serious complication that can result when instruments are inadvertently placed between the cervical lamina. To minimize this risk, we recommend slowly advancing the K-wire under fluoroscopic control and removing the K-wire after the first dilator is placed over the wire. Do not wait until all dilators are in place because passing each sequentially larger dilator adds the risk of potentially plunging the K-wire in between the lamina or through a small laminar defect.

Placement of the K-wire and subsequent muscle dilators should always be performed using a gentle rotating downward action under spot fluoroscopic guidance. The K-wire is removed after the first muscle dilator is passed. Additionally, particularly in repeated operations in which dense scar tissue and muscle atrophy may exist, not forcefully pushing the K-wire and/or muscle dilators toward the spine can help reduce inadvertent entry into the canal or nerve injury. Typically the K-wire, subsequent muscle dila-

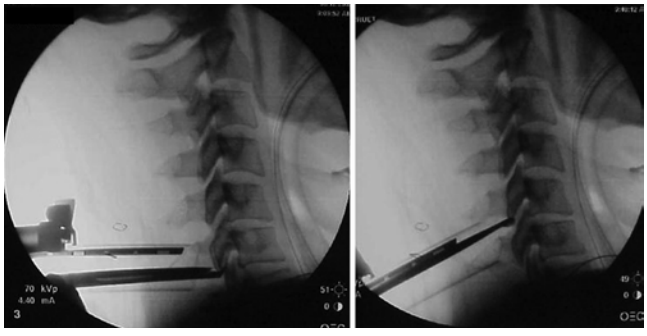


Fig. 1. Intraoperative lateral fluoroscopic views of the cervical spine with proper dilator docking on the laminofacet complex during a minimally invasive posterior forminotomy.

tors, and tubular retractor are docked approximately 1 cm dorsal to the spine. The remainder of the approach is then performed under direct visualization through the operative microscope starting laterally to identify bone landmarks first. Anterior-posterior fluoroscopic images can be obtained to ensure proper laterality with respect to docking on the correct facet complex. This image can also be used to ensure that one is not docking too laterally because of the risk of injury to the vertebral artery. Vertebral artery injury is very rare and, although primary repair of vertebral artery injury has been described, the procedure itself can prove to be technically difficult. Alternatively, bleeding can be controlled with gentle pressure and packing with muscle or Gelfoam. Postoperative angiography should be performed to rule out pseudoaneurysm or arteriovenous fistula formation.

After appropriate exposure, the posterior cervical fascia should be cut primarily to avoid the need to place the K-wire and subsequent muscle dilators through the fascia with undue pressure. Once this fascia is cut, the K-wire and the muscle dilators can be carefully rotated through the fascial incision to the docking location (Fig. 1). Even though the chance of inadvertent spinal cord injury is significantly reduced, this does not obviate the need for frequent lateral fluoroscopic imaging to assess progress toward the spine. During the foraminotomy, excessive root manipulation can result in root injury, especially for the C-5 and C-8 nerve roots. This often occurs more with repeat operations when adhesions and scar tissue are adherent to the nerve roots. These deficits usually resolve with time, but care should be taken if manipulation is required.

Cerebrospinal fluid leak was reported as the most common complication in the retrospective review of Adamson[2] of 100 cases of posterior cervical forminotomy. These leaks typically resolve with 2–3 days of lumbar drainage. If the dural violations can be visualized in the operating room, primary repair can be attempted or Gelfoam or DuraGen placement along with fibrin glue can be performed. If this complication occurs, a meticulous fascial closure is preformed and the skin closed with a running locking nylon suture.

Thoracic Procedures

Anterior Thoracic Procedures

Advances in thoracoscopic instrumentation have led to the development of new anterior approaches to the thoracic spine that were either extremely technically difficult or impossible previously. Cervical and lumbar pathology is more common than thoracic disease, but the true incidence of thoracic pathology has been traditionally underestimated. More recent studies have shown that thoracic disc herniations comprise 14.5% of all disc herniations.[27] While the vast majority of these herniations are asymptomatic, those cases that are symptomatic are usually quite serious, involving myelopathy and long tract signs or severe thoracic radicular pain syndromes. Advantages of the minimally invasive approaches compared with open thoracotomy are a lower incidence of intercostal neuralgia and chest pain along with respiratory complications, such as postoperative effusion, scarring, and atelectasis. In the largest series of thoracoscopic discectomies,[26] the authors reported less approach-related morbidity than an unmatched cohort undergoing excision using thoracotomy. Other complications that can arise with thoracoscopy are related to anesthesia, positioning, port placement and closure, and manipulation of long instruments within the thoracic cavity with the concomitant risks to vascular and lung parenchymal structures. To avoid this type of injury, close attention must be given to preoperative workup, including positioning. Candidates should be selected based on health status and the ability to tolerate single-lung ventilation. Patients with baseline respiratory compromise will have difficulty tolerating the ventilation/perfusion (V/Q) mismatch for even brief periods of time. To reduce organ injury during port placement, all ports after the initial one should be placed under direct endoscopic visualization. When the lung is collapsed, the diaphragm and subdiaphragmatic organs may elevate with the thoracoabdominal cavity slightly. The surgeon should keep this change in mind when correlating the surface anatomy and intraabdominal anatomy when placing the lower ports. Bleeding at port sites almost always resolves without special intervention. However, continued bleeding should be managed with bipolar coagulation and irrigation. The incidence of hemothorax in these cases has been reported to be between 0% and 5%.[15,17,20] A Foley balloon can be inflated to temporarily tamponade a bleeding site until the source is identified. An unrecognized injury to the azygos vein or an intercostal vessel may require a thoracotomy for proper control.

Recently, the mini-thoracotomy approach has been introduced as another choice for surgeons who need a larger exposure, but do not want to subject patients to the morbidity of a full thoracotomy. Improved retractors allow for excellent minimally invasive thoracic exposure (Fig. 2). Expandable vertebral body cage reconstruction technology has also facilitated this technique. This approach can potentially reduce morbidity compared with more open traditional thoracotomy techniques. Complications associated with this technique are similar to those encountered with traditional thoracotomy approaches and include lung atelectasis and great vessel and spinal cord injury. Early exposure of the spinal cord by drilling of the rib head and underlying pedicle can access and expose the spinal cord to orient the surgeon. Compression of the spinal cord by large disc fragments can be managed by first preparing space into which the herniated disc fragment can be pushed into,

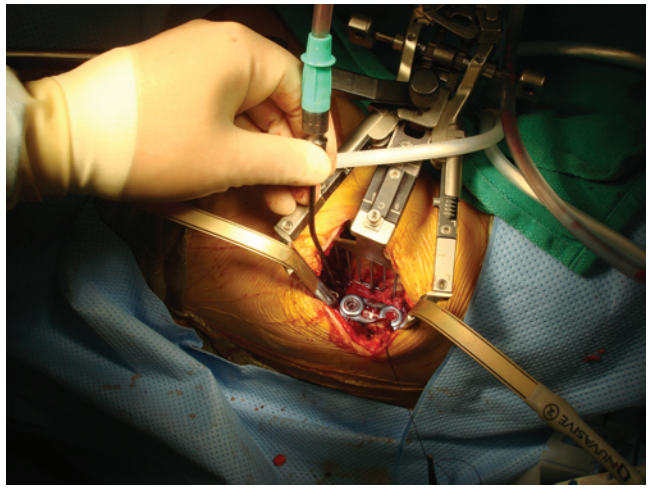


Fig. 2. Intraoperative photograph showing the mini-thoracotomy retractor system in place, which has a low profile and fiberoptic light cables to improve visualization. The thoracic plate construct can be observed through the retractor blades.

away from the spinal cord. The surgeon should anticipate dural violation where large calcified disc herniations are present. If CSF is encountered, the repair can be done primarily, although it will be difficult because the dural tear is often macerated due to the calcified disc adherence. We typically suture a dural patch graft over the opening and then cover with fibrin glue. If needed, a lumbar drain can be placed to divert CSF flow to allow for healing of the defect. In rare cases, a lumboperitoneal shunt is placed to prevent persistent CSF leak into the chest cavity.

Posterior Thoracic Microdiscectomy

The main advantage of using a posterior thoracic microdiscectomy is that it can be performed via a posterior muscle-splitting approach, avoiding the much more morbid transthoracic approach that requires reconstruction and instrumentation. It is ideal for soft lateralized disc herniations, and patients can frequently be discharged within a day. Calcified disc herniations can be identified with preoperative CT/myelogram study using localizing radiographs taken from the sacrum to the level of the pathology for accurate intraoperative localization. Preoperative chest, thoracic, and lumbar anteroposterior and lateral radiographic images are obtained for intraoperative level localization. Adequate fluoroscopic visualization and level localization are of paramount importance. Several techniques for localization such as counting from the sacrum up or counting ribs are used. Evaluation of the preoperative MR imaging or CT scan will determine how laterally the thoracic incision should be made in order to be able to dock on the facet at the level of interest. K-wire and serial muscle dilators are placed under fluoroscopic guidance. The lateral aspect of the facet complex is exposed and drilled to expose the lateral aspect of the dura. By exposing the lateral aspect of the dura, the orientation of the spinal cord is appreciated by the surgeon. After the annulotomy is performed, the discectomy can be started. Disc removal provides the surgeon with more room within the disc space to push herniated disc fragments away from the spinal cord and avoid manipulation of the spinal cord, which could lead to cord injury. Brisk bleeding can be encountered from engorged epidural drains. Gelfoam, or more recently introduced hemostatic agents, can help to control this bleeding. Micropituitary and downgoing curettes are used to facilitate disc removal and avoid cord manipulation.

Lumbar Procedures

Minimally Invasive Microdiscectomy and Laminectomy

Recent advances in tubular dilators and optics for visualization have produced several instrumentation sets and techniques for minimally invasive access to posterior lumbar lesions. Proper docking of the K-wire on the laminofacet complex under strict fluoroscopic guidance as the instrument is advanced is critical to avoid placement of the K-wire between adjacent lamina and risk spinal cord and nerve root injury. With proper exposure of the ipsilateral lamina, drilling of bone is then performed. In the case of a decompressive laminectomy, the ligamentum flavum is maintained to avoid injury to the dura with the drill bit. The decompression is started at the more caudal portion of the lamina under which the ligamentum flavum is located. More rostral on the ipsilateral lamina, drilling is performed to expose the rostral edge of the ligamentum flavum that ends medially. This medial portion marks the midline of the canal and serves as a useful anatomical landmark to the medial portion of the canal. Once adequate ipsilateral decompression is performed, the patient is tilted away from the surgeon by 5°–10°, the retractor is moved and properly oriented to view the base of the spinous process, and the spinous process and contralateral lamina are undercut with the drill (Fig. 3). We prefer to use a long, thin, electric

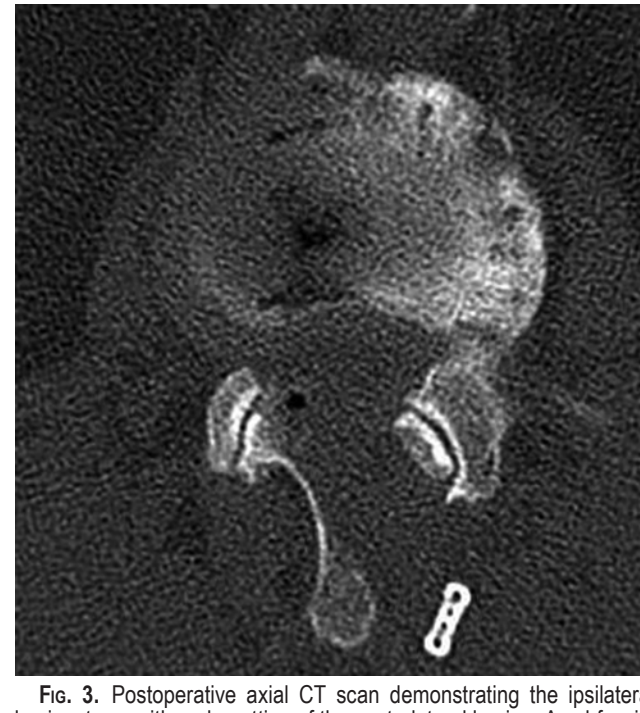


Fig. 3. Postoperative axial CT scan demonstrating the ipsilateral laminectomy with undercutting of the contralateral lamina. A subfascial drain is placed for multilevel decompression to prevent postoperative hematoma accumulation.

drill because it does not obstruct the surgeon's view, operates smoothly with the push of a foot pedal, and allows for adequate contralateral decompression. If a durotomy is encountered, a small collagen barrier patch such as Duragen and fibrin glue can be applied. It is difficult to repair a dural tear through a small tubular retractor. With large dural violations, the operation may have to be converted to an open procedure and the dura repaired primarily with subsequent lumbar drainage. In these cases, a meticulous fascial closure is performed and the skin reapproximated with a running nylon suture. When these precautions are taken, a delayed postoperative pseudomeningocele is rare.

After bone decompression is performed, the hypertrophied ligamentum flavum is removed. The ipsilateral portion of the ligamentum flavum that underlies the ipsilateral lamina is removed first. This allows more room in the canal to remove the contralateral ligament. Using a small upgoing curette, the contralateral ligamentum flavum is removed with the use of a No. 2 Kerrison punch. It is at this location that most durotomies occur. Using an upgoing curette to detach the ligamentum flavum from any dural adhesions before removing it can help to reduce the incidence of durotomies. Minimally invasive decompressive laminectomy has an excellent clinical outcome because it can be performed with minimal tissue disruption.

Transforaminal Lumbar Interbody Fusion

Minimally invasive spinal fusion can be performed from a lateral, anterior, transsacral, or posterior approach. We will focus on the posterior or transforaminal lumbar interbody fusion approach in this section. During the approach, the facet complex is drilled to approach the disc space. The lateral edge of the dura is identified to avoid injuring the traversing nerve root, and enough of the facet is removed to properly place graft material into the disc space without excessive retraction on the nerve root. In many instances, almost the entire facet complex might need to be removed. Neurapraxic injury to the nerve root can occur during interbody preparation and graft placement. This is avoided by removing an adequate amount of the facet so that instruments can be passed safely into the interspace (Fig. 4). Expandable interbody devices have been developed that can limit the amount of bone removal and nerve root retraction necessary because the devices are expanded once inside the disc space.

In higher-grade spondylolisthesis cases, care is taken to avoid injury to the exiting nerve root that can be pushed more medially as it is stretched over the disc space. First identifying the traversing nerve root and then removing bone more laterally over the disc space can help to prevent injury to the exiting nerve root. The realization that the exiting nerve root passes around the medial then caudal portion of the pedicle of the more rostral vertebral body helps to prevent exiting nerve root injury. Interbody placement in these cases can markedly reduce a spondylolisthesis and restore foraminal height and canal diameter in degenerative disc cases (Fig. 5).

In situations in which the disc space is markedly collapsed, a distractor chisel can be placed into the disc space and then rotated 90° to help restore disc space height. Care is taken to avoid advancing any of the interbody disc space cleaning instruments beyond 30 mm to avoid violation of the anterior annulus border of the disc and risking injury to the bowel or intraabdominal vascular structures. Lateral fluoroscopic imaging is useful in determining the depth of instruments within the disc space (Fig. 4). If brisk arterial bleeding is encountered and a major abdominal blood vessel injury is suspected, the interspace can be quickly packed with Gelfoam, emergency vascular consultation requested, the wound superficially closed with staples, the patient repositioned supine, and an emergency laparotomy performed. If a bowel injury is suspected, a gastrointestinal surgeon should be consulted and emergency laparotomy performed to inspect the bowel and repair perforations. Patients with bowel injury undetected at the time of surgery will frequently have considerable abdominal pain and guarding in the postoperative period. Further investigation of bowel injury using CT and/or the identification of free air within the abdomen using lateral decubitus radiography is warranted.

Recent 5-year long-term outcome data have been reported with a cohort of 98 patients undergoing minimally invasive transforaminal lumbar interbody fusion (Perez-Cruet M, Hussain NS, Hiremath G, et al: Long-term prospective analysis of minimally-invasive transforaminal lumbar interbody fusion and percutaneous pedicle screw

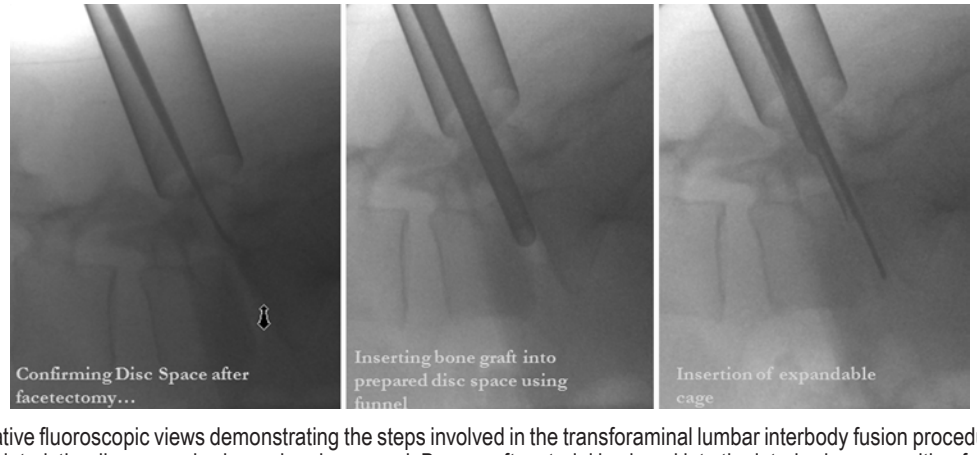


Fig. 4. Intraoperative fluoroscopic views demonstrating the steps involved in the transforaminal lumbar interbody fusion procedure. After a unilateral facetectomy is completed, the disc space is cleaned and prepared. Bone graft material is placed into the interbody space with a funnel and an expandable cage can be placed.

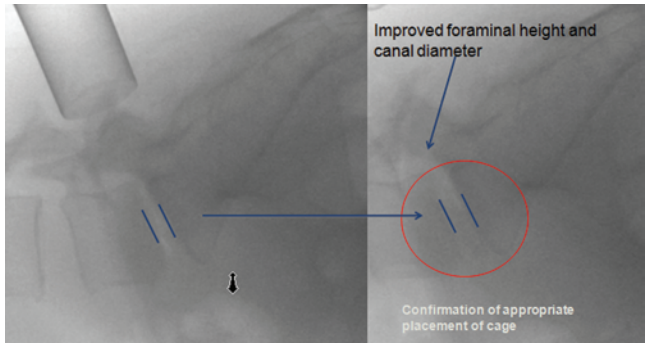


Fig. 5. Intraoperative fluoroscopic views showing the degree of foraminal and disc height restoration with interbody device placement during transforaminal lumbar interbody fusion.

placement. Paper presented at the AANS/CNS Section on Disorders of the Spine and Peripheral Nerves Annual Meeting, Phoenix, Arizona, March 9–12, 2011). Patients experienced statistically significant improvements across all clinical outcomes measures. For the entire patient cohort, complications included cases that required reoperation, as well as other complications. Of the cases that required reoperation, 2 (2%) had instrument failure, 2 (2%) had adjacent segment disease, and 2 (2%) had nonadjacent segment disease. Other complications included neurological deficit in 2 patients (2%), surgical site infection in 1 patient (1%), nonsite infection (urinary tract infection or pneumonia) in 3 patients (3%), postoperative atrial fibrillation in 1 patient (1%), and fever (no source identified) in 3 patients (3%).

Percutaneous Spine Techniques

There are 3 categories of percutaneous spine techniques that are of interest to this discussion: vertebroplasty, kyphoplasty, and percutaneous screw placement. Vertebroplasty and kyphoplasty have gained popularity as useful minimally invasive procedures to treat painful osteoporotic compression fractures. The most common complications reported are pain, radiculopathy, cord compression, adjacent-level vertebral body collapse, and venous embolism.[7] Most mass-effect complications have been linked to cement leakage.[9] There have been reports of an increased incidence of cement leakage and adjacent vertebral body fracture with kyphoplasty. Investigators have hypothesized that this may be due to the high-pressure system required for balloon inflation during kyphoplasty. Agris et al.[3] have reported a statistically significant difference in cement leakage rate—9.7% for vertebroplasty and 11.7% for kyphoplasty—but several more contemporary series dispute this.[13] Differences in the data may be due to recent improvements in technique and instrumentation for kyphoplasty.

In avoiding complications and nerve root injury when placing percutaneous pedicle screws, there are several techniques that can be used. Perhaps the most critical step is adequate fluoroscopic visualization of the targeted pedicle in the anteroposterior view. The endplate of the target vertebrae should be 1 line so that the C-arm gantry is looking straight down the pedicle. This ensures that opposite endplates are lined up. The next steps involve targeting the

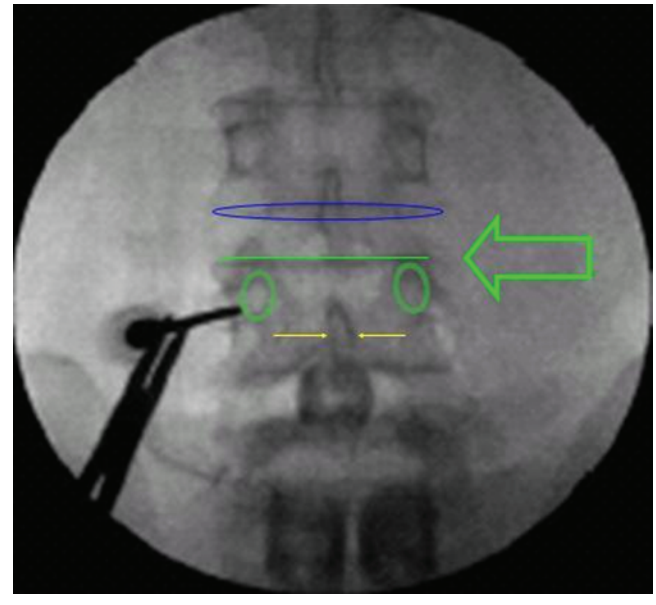


Fig. 6. Anteroposterior fluoroscopic view showing proper pedicle targeting and aiming the needle in a lateral to medial direction. *Green circles* represent the pedicles, *green line* indicates the superior endplate of the vertebral body, *yellow arrows* point to the spinous process (which should be midline when obtaining a proper anteroposterior radiograph), *green arrow* points to the endplate of the targeted vertebrae, and *blue circle* indicates the inferior endplate of the vertebral body above.

pedicle and driving a Jamshidi needle through the pedicle in a lateral-to-medial direction, followed by the K-wire (Fig. 6). The K-wire can be removed inadvertently during Jamshidi needle removal. This problem can be avoided by having an assistant hold the K-wire while the Jamshidi needle is carefully removed from the pedicle using a gently upward twisting motion on the Jamshidi needle.

Any time during K-wire advancement, the wires can be stimulated to ensure they are not touching or irritating a nerve root. An action potential of 8 mA or less might warrant repositioning the K-wire.

Once the K-wires are in place and positions are confirmed, the pedicle is tapped. To avoid the complication of advancing or dislodging the K-wires, an assistant holds the K-wire with a Kocher clamp while passing cannulated instruments over the K-wire. Care is taken to clean all cannulated instruments by passing a K-wire through the cannula, especially the pedicle tap, before placing them over the implanted K-wire. After the screw is inserted and in its proper place, the K-wire can get stuck and become difficult to remove. This frequently occurs because the K-wire tip bends as the pedicle screw follows the path of the softer cancellous core of the pedicle. If this happens, simply grab the K-wire with a Kocher clamp at its base and hit up with a mallet to dislodge the K-wire. Backing the screw out a few millimeters with a hand drill before grabbing the K-wire with a Kocher clamp can help as well. In most cases, a screw length of 45 mm is an adequate length and does not perforate the anterior cortical margin of the vertebrae. Using this technique, instrumentation strength appears sufficient to achieve adequate arthrodesis while minimizing cortical breaches (Perez-Cruet M, Hussain NS, Hiremath G, et al: Long-term prospective analysis of minimally-in-

vasive transforaminal lumbar interbody fusion and percutaneous pedicle screw placement. Paper presented at the AANS/CNS Section on Disorders of the Spine and Peripheral Nerves Annual Meeting, Phoenix, Arizona, March 9–12, 2011). Pedicle screw stimulation using electromyographic monitoring is then performed. Those screws that stimulate at less than 8 mA are repositioned. In most cases this can be performed easily without having to abandon that pedicle for screw placement.

In terms of accuracy of the pedicle screw placement, authors of a recent meta-analysis of 130 studies,[16] involving a total of 37,337 pedicle screws implanted, reported accurate placement of 34,107 screws for a 91.3% accurate placement rate. Three-dimensional neuronavigation has been shown to increase accuracy rates for percutaneous pedicle screw placement.[12] Additionally, percutaneous screw placement does not require extensive muscle dissection, and patients develop much less scarring and atrophy of the paraspinous musculature (Fig. 7) and are left with a much smaller incision (Fig. 8). Because there is less muscle trauma and the surgical incisions are smaller with pedicle screw placement, a lower infection rate is encountered, particularly in obese patients with associated diabetes. Because there is less blood loss and tissue damage, recoveries are generally faster, patients can begin to ambulate, and they are discharged from the hospital sooner. This relatively faster recovery can be a factor in reducing complication rates, especially in the obese patient population.

Transpsoas Interbody Fusion

The transpsoas interbody fusion procedure was developed to provide a lateral retroperitoneal approach to achieve spinal fusion in the lumbar spine. The procedure is especially useful for correction of coronal plane deformities[1] (Fig. 9). Possible complications that can occur include inadvertent entry into the peritoneal cavity and subsequent bowel injury while placing dilators. Careful patient positioning and the use of 2 fingers to bluntly dissect to create space in the retroperitoneal area can help to avoid this complication. This approach is used for fusions above the L5–S1 segment because the iliac crest does not allow access to the L5–S1 interspace. The psoas muscle may be injured during dissection with the muscle dilators to reach

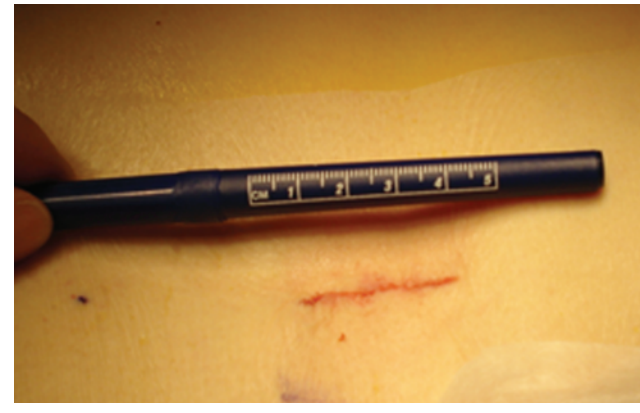


Fig. 8. Minimally invasive approaches to the spine require only small incisions and can be cosmetically appealing. Shown is the immediate postoperative skin closure after a multilevel (3 levels) minimally invasive laminectomy.

the disc space. Injury can result in patients experiencing flexor weakness on the side of the approach postoperatively; this weakness is observed in approximately 10% of patients and generally resolves in days to weeks. Patients should be advised of this possible complication and that it generally resolves. Early rehabilitation can help to alleviate this condition.

The psoas muscle contains the lumbosacral plexus posteriorly and the genitofemoral nerve anteriorly. Retraction of the psoas can cause transient postoperative thigh pain, numbness, paresthesias, and weakness due to injury to these nerves as they exit the spine laterally. A recent study[10] followed 59 patients over a 3-year period, with 62.7% having thigh symptoms postoperatively. New thigh symptoms at initial follow-up included burning, aching, or pain in 39%, numbness in 42.4%, paresthesias in 11.9%, and weakness in 23.7%. The number of levels treated had no clear association with thigh symptoms. Half of these patients with complications had symptom resolution at 3 months postoperatively. More than 90% experienced symptom resolution by 1 year.

Cadaveric studies have described safe working zones when performing the transpsoas approach.[5,19,23] Between the L1–2 and the L3–4 disc spaces, a safe working area

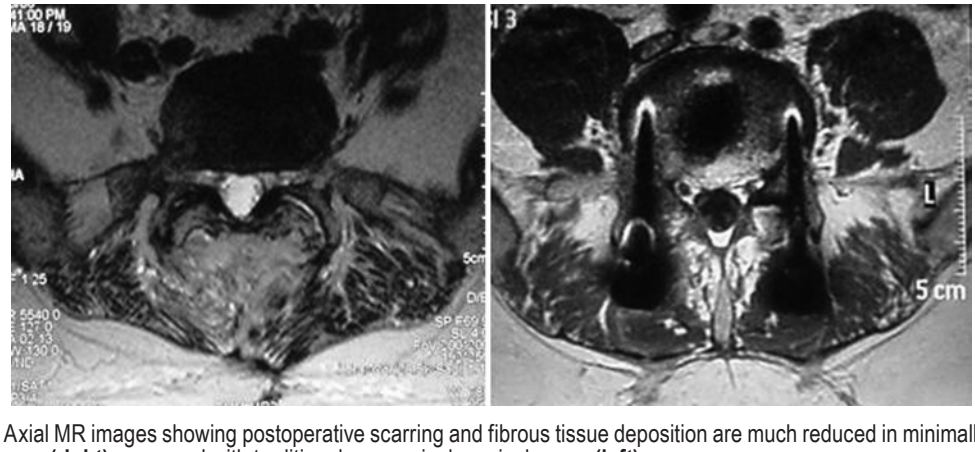


Fig. 7. Axial MR images showing postoperative scarring and fibrous tissue deposition are much reduced in minimally invasive surgical cases **(right)** compared with traditional open spinal surgical cases **(left)**.



Fig. 9. Anteroposterior radiographs demonstrating the excellent coronal deformity correction that can be achieved with the transpsoas interbody approach.

is near the middle posterior quarter of the vertebral body. At the L4–5 disc space, the safest working zone is at the midpoint of the vertebral body. There is also a potential risk of injury to the ilioinguinal, iliohypogastric, and lateral femoral cutaneous nerves in the retroperitoneal space where they travel obliquely. To help reduce nerve injury, various electrophysiological monitoring systems can be used that use muscle dilators attached to a monitoring unit. Additionally, instruments are used that can monitor the area retracted to ensure that no neural elements are present under or adjacent to the retractor or dilator. These electrophysiological monitoring tools have contributed to decreasing the serious complication rate from plexus injury from 30% to less than 1%.[24] Repositioning the tissue or retractor can avoid permanent neural injury when neural elements are nearby. This approach affords an indirect decompression of the neural elements. The lateral approach allows for a relatively large implant to be placed into the disc space, similar to an anterior lumbar interbody fusion technique. Thus, the foraminal height can be restored and in many cases the canal decompressed as well. Supplemental instrumentation can be applied via a lateral approach, or posteriorly using percutaneous pedicle screws or facet fixation. In certain cases, a separate posterior decompression is required. There have been scattered reports about the usefulness of the transpsoas approach including a series of 13 patients encountering no complications.[18] Other series have reported ureter injury, in which case patients should undergo urological consultation with possible dye study to confirm the injury.

Transsacral Approach

The transsacral approach was developed to avoid injury to the posterior musculature and avoid the need for a transabdominal approach. This approach is indicated to achieve an L5–S1 fusion. Recent developments in the technique have shown that L4–5 fusion can be performed in combination with the L5–S1 level. The primary complication concern is bowel injury because the approach is through the fat pad between the rectum and the sacrum. To reduce this possible complication, a bowel preparation is given to the patient before the surgery. Additionally, those patients with conditions that make the mobilization of the bowel under the sacrum difficult or not possible should be avoided. Therefore, patients with a suspected medical history that could lead to excessive abdominal adhesions, such as multiple prior abdominal surgeries, inflammatory bowel disease, endometriosis, or diverticulitis, should be treated via other approaches.

A careful analysis of preoperative imaging will help to ensure that the angulation of the sacrum with respect to the lumbar vertebrae is adequate to achieve access to the L5–S1 interspace. Blunt dissection on the underside of the sacrum can help to avoid bowel injury. The instruments are specifically designed to allow safe docking on the S1–2 area and introduction of a working channel to pass instruments. Nitinol shavers are introduced through a working channel and circumferential cleaning of the disc space is performed for graft material placement and screw deployment. To avoid pseudoarthrosis, care is taken to adequately prepare the disc space. Bone morphogenetic protein could potentially improve fusion results without involving issues of heterotopic bone formation encountered in more open techniques using bone morphogenetic protein, because this approach affords relative isolation of bone morphogenetic protein sponge application. In a long-term follow-up of 35 patients, bone fusion was achieved in 91% of patients with no reported complications occurring.[4]

Conclusions

Recent advances in technology, surgical techniques, and anesthesia have lead to new advances in the procedures that we can offer our patients. The literature reporting complications with minimally invasive procedures is limited due to the lack of long-term outcome data. As more data become available, we will have a stronger case with regard to recommending these techniques over traditional open surgeries. These procedures will continue to reduce hospital stays and costs provided that patients are carefully selected and thoroughly educated prior to surgery. Minimally invasive spine procedures do offer clinical advantages that have improved outcomes, but there is a steep learning curve with regard to mastering these techniques. Proper patient selection and surgeon education and training will help to match the proper patient to the proper surgery for the best outcomes and reduced complications.

Disclosure

Dr. Perez-Cruet is a patent holder with MI4Spine, LLC, and Thompson MIS, and serves as a consultant to Zimmer Spine and Aesculap Spine.

Author contributions to the study and manuscript preparation include the following. Conception and design: both authors. Acquisition of data: both authors. Analysis and interpretation of data: both authors. Drafting the article: both authors. Critically

revising the article: both authors. Reviewed submitted version of manuscript: both authors. Approved the final version of the manuscript on behalf of all authors: Hussain. Statistical analysis: both authors. Administrative/technical/material support: both authors. Study supervision: both authors.

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Manuscript submitted June 15, 2011.
Accepted August 10, 2011.

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Neurosurg Focus 31 (4):E3, 2011

Complications and outcomes after spinal deformity surgery in the elderly: review of the existing literature and future directions

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Object. The elderly population (age > 60 years) is the fastest-growing age group in the US. Spinal deformity is a major problem affecting the elderly and, therefore, the demand for surgery for spinal deformity is becoming increasingly prevalent in elderly patients. Much of the literature on surgery for adult deformity focuses on patients who are younger than 60 years, and therefore there is limited information about the complications and outcomes of surgery in the elderly population.

In this study, the authors undertook a review of the literature on spinal deformity surgery in patients older than 60 years. The authors discuss their analysis with a focus on outcomes, complications, discrepancies between individual studies, and strategies for complication avoidance.

Methods. A systematic review of the MEDLINE and PubMed databases was performed to identify articles published from 1950 to the present using the following key words: "adult scoliosis surgery" and "adult spine deformity surgery." Exclusion criteria included patient age younger than 60 years. Data on major Oswestry Disability Index (ODI) scores, visual analog scale (VAS) scores, patient-reported outcomes, and complications were recorded.

Results. Twenty-two articles were obtained and are included in this review. The mean age was 74.2 years, and the mean follow-up period was 3 years. The mean preoperative ODI was 48.6, and the mean postoperative reduction in ODI was 24.1. The mean preoperative VAS score was 7.7 with a mean postoperative decrease of 5.2. There were 311 reported complications for 815 patients (38%) and 5 deaths for 659 patients (< 1%).

Conclusions. Elderly patient outcomes were inconsistent in the published studies. Overall, most elderly patients obtained favorable outcomes with low operative mortality following surgery for adult spinal deformity.
(DOI: 10.3171/2011.7.FOCUS11145)

Key Words • spinal deformity • elderly • complication • outcome • minimally invasive • future direction

Adult spinal deformity is a significant problem for many patients, in particular, the elderly. The elderly (defined here as those aged 60 years and older) is the fastest-growing demographic in the US. Currently estimated to be 12.4% of the population, the number of elderly patients has been projected to increase to 19.6% by the year 2030.[20] Spinal deformity is a major morbidity in this population, with pain and balance problems associated with spinal deformity often representing a significant obstacle to mobility in this age group.[8] In a recent study, Schwab et al.[50] reported a prevalence of spinal deformity as high as 68% in those older than 60 years. Of all patients hospitalized with a diagnosis of spinal deformity, 50% were 65 years and older.[3,29]

Nonsurgical management for spinal deformity in the elderly is likely underreported. While it is hypothesized that a majority of spinal deformity patients are treated nonoperatively by their primary physicians, an increasing number of patients are opting for surgery.[23] The goals of surgery are to halt the progression of the deformity, restore the sagittal and coronal balance, optimize cosmesis, and improve neurological function.[1] Unlike most spine disease processes, spinal deformity is a complex entity comprising more than one problem. Thus, complete deformity correction is often not possible and should not be considered the goal. Rather, surgery seeks to alleviate the symptoms of the existing deformity while preventing further deformation.[1,48]

Surgical morbidity and mortality have been shown to be higher in the elderly. Therefore, preoperative evaluation of these patients is particularly important. Specifically, the presence of coexistent disease and reduced physi-

Abbreviations used in this paper: DEXA = dual-energy x-ray absorptiometry; ODI = Oswestry Disability Index; VAS = visual analog scale.

ological reserve have been shown to adversely affect outcomes in elderly patients.[6,28,39] Studies have demonstrated that preoperative tests of pulmonary, renal, and cardiac functioning are at least partially predictive of postoperative complications associated with these organ systems in elderly patients.[6,31,36,37,46,57] Furthermore, malnutrition has also been indicated as a risk factor for postoperative nosocomial infections in elderly patients; nutritional status should therefore be evaluated and managed appropriately prior to operating.[26,32,34,40,49,58]

Considering the increased demand for scoliosis surgery by the elderly, it is important to conduct clinical studies with long-term follow-up to assess the best way to manage surgical complications and strategies to avoid these complications. To provide insight into what has already been researched, we reviewed and analyzed the published studies involving patients > 60 years of age who underwent surgery for scoliosis. The specific aims were to assess whether the deformity treatment is beneficial to the elderly based on patient-reported and standard clinical outcomes and to understand the frequency and type of complications that are encountered.

Methods

Literature Review

A query of the PubMed and MEDLINE databases was performed to identify articles pertinent to spinal deformity surgery in the elderly published between 1950 and 2011. An initial search using the key words "adult scoliosis surgery" and "adult spine deformity surgery" returned 3106 articles. The query was further limited to the English-language literature (2595 articles) and a patient age of 60 years or older (733 articles). Abstracts from these articles were reviewed by 2 separate authors (D.D. and M.S.). This yielded 129 articles for detailed review.

Of these 129 articles, 107 were excluded from analysis because of failure to meet the patient age criteria or report postoperative outcomes. The remaining 22 articles were included in the analysis. Articles were reviewed for data on methodology (retrospective vs prospective), number of patients, mean patient age, and mean follow-up. Clinical outcomes data based on postoperative ODI scores, change in ODI scores from preoperative, postoperative VAS instrument scores, and change in VAS scores from preoperative was also recorded when available. Because studies often used differing definitions of major and minor complications, all complications were grouped and the total rate of complications calculated.

Statistical Analysis

All descriptive statistics were calculated using JMP 7.02 (SAS Institute). Averages for age, length of follow-up, and changes in ODI and VAS scores were calculated. Additionally, studies that reported patient-reported outcomes were summarized. Complications were calculated by adding up the total number of reported complications and dividing this number by the total number of patients experiencing complications. The incidence of mortality was similarly calculated by totaling the number of deaths and dividing this number by the number of patients who died.

Results

The review included 22 articles with data reported for 1417 patients. Four studies were conducted prospectively, and 18 studies were conducted retrospectively. The mean patient age was 74.2 years, and the average follow-up period was 3 years. Two studies did not report the average patient age, and 5 studies did not report the average follow-up period.

Seven studies comprising 262 patients reported a mean preoperative ODI of 48.6 (Table 1). Seven studies comprising 252 patients reported a mean postoperative ODI of 25.4. The average same-study decrease was 24.1. Eight studies consisting of 363 patients reported a mean preoperative VAS score of 7.7. Seven studies consisting of 335 patients reported a mean postoperative VAS score of 2.5. The average same-study decrease was 5.2.

Eight studies that included patient-reported outcomes were also examined (Table 2). These studies included a total of 808 patients. On average, 73.1% of patients reported outcome following surgery as "excellent/good," 15.2% as "fair/unchanged," and 13.4% as "poor/worse."

Because studies often used differing definitions of major and minor complications, all complications were grouped and the total rate of complications calculated. A total of 311 complications were reported by 14 studies including 815 patients to give an overall complication rate of 38% (Table 3). Mortality was reported by 13 studies and averaged 0.85%.

All studies of corrective procedures reported improvement of deformity from radiographs obtained immediately postoperatively to the final follow-up. There were only 2 studies that reported preoperative and postoperative degrees of correction. Specifically, Li et al.[35] reported a 44% Cobb angle improvement from a mean 35.1° of preoperative deformity to 23.25° at final follow-up. In 2010, Di Silvestre et al.[18] reported a 37.5% scoliosis improvement from a mean of 16.9° to 11.1° at final follow-up.

Progressive junctional kyphosis was reported in 2 studies reviewed for this paper. DeWald and Stanley[17] reported progressive junctional kyphosis in 26% of patients (10 of 38) with construct lengths ranging from 6 to 8 levels and terminal cephalad levels ranging from T-10 to L-1. Daubs et al.[15] reported progressive junctional kyphosis in 2% of patients (1 of 46) adjacent to their most cephalad level of fusion.

Four studies reported reoperation rates. Daubs et al.[15] reported 15 patients (32%) who required additional procedures (for example, misplaced pedicle screw, prominent implants, pseudarthrosis, and progression of scoliosis). DeWald and Stanley[17] reported an 11% reoperation rate for patients who developed pseudarthroses with rod breakage, acute disc herniation at the disc space directly above the construct, and painful instrumentation requiring removal of a multilevel segment. Rosen et al.[45] reported that 2% of patients required reoperation for additional decompression and fusion, while Li et al.[35] reported a 3% revision rate at 1 year.

TABLE 1: Literature review of clinical outcomes and complications for elderly patients undergoing surgery for scoliosis*

Authors & Year	Study Design	No. of Pts	Mean Age (yrs)	Mean FU (yrs)	ODI		VAS Score		No. of Complications	Mortality (%)
					Preop	Postop	Preop	Postop		
Benz et al., 2001	retrospective	68	76.5	3.5	NA	NA	NA	NA	32	1.5
Bess et al., 2009	retrospective	28	73.2	NA	49	NA	7.8	NA	NA	NA
Best & Sasso, 2007	retrospective	127	73.2	4.6	NA	NA	8.8	1.8	NA	NA
Cassinelli et al., 2007	retrospective	166	73.3	NA	NA	NA	NA	NA	61	0
Daubs et al., 2007	retrospective	46	67	4.2	49	25	NA	NA	37	2.2
DeWald & Stanley, 2006	retrospective	38	72.4	2.5	NA	NA	NA	NA	24	0
Galiano et al., 2005	retrospective cohort	19	82.2	2.7	NA	36.4	8.5	3.9	NA	17
Jo et al., 2010	retrospective	48	71.2	2	NA	NA	7.1	2.8	11	0
Kilinçer et al., 2005	retrospective	40	73	1	NA	NA	NA	NA	5	0
Li et al., 2009	retrospective	34	75.1	2.8	45	18	NA	NA	6	0
Raffo & Lauerman, 2006	retrospective	20	NA	2.6	NA	NA	NA	NA	13	0
Ragab et al., 2003	retrospective	118	74	NA	NA	NA	NA	NA	24	NA
Rosen et al., 2007	prospective	57	81	0.8	48	27	5.7	2.2	22	NA
Scheufler et al., 2010	prospective	30	73.2	1.6	57.2	24.8	7.5	2.6	NA	NA
Shabat et al., 2008	prospective	25	83.95	3.1	NA	NA	8.8	3.6	23	0
Di Silvestre et al., 2010	retrospective	29	68.5	4.5	51.8	27	6.7	3.3	8	0
Smith et al., 2011	retrospective	38	70	2	43	24	NA	NA	27	0
Wang et al., 2003	retrospective	88	78.5	NA	NA	NA	NA	NA	18	0

* FU = follow-up; NA = not available; Pts = patients.

Discussion

Adult deformity is a significant problem for many patients. The majority of patients seek nonsurgical treatment.[23] Many surgical treatment strategies exist, and the type of reconstruction that is necessary is patient specific. However, surgical options for elderly patients are limited by medical comorbidities, the ability to tolerate a long operation, and life expectancy. Interestingly, the elderly have been shown to significantly benefit from surgery in terms of improvements in symptoms.[55]

The aim of the current study was to provide analytical data regarding scoliosis surgery in the elderly population. The current review focused on the ODI, VAS scores, and patient-reported outcomes, the most consistently used measures. Complications and strategies for complication avoidance were included in this review.

Clinical Outcome

Among the elderly, patients most likely to receive significant alleviation of symptoms tended to have higher levels of deformity and increased disability.[18,35,41,47,51,54] High ODI, high VAS scores, and low 12-Item Short Form Health Survey (SF-12) scores were associated with an improvement in symptoms. A baseline SF-12 score of 35

TABLE 2: Literature review of postoperative patient-reported outcomes for elderly patients undergoing surgery for scoliosis

Authors & Year	Study Design	No. of Pts	Mean Age (yrs)	Mean FU (yrs)	Outcome (%)		
					Excellent/Good	Fair/Unchanged	Poor/Worse
Arinzon et al., 2004	retrospective	152	72	3.5	65	20	15
	retrospective	83	81.4	3.6	71	19	10
Benz et al., 2001	retrospective	68	76.5	3.5	60	19	21
Best & Sasso, 2007	retrospective	136	73.2	4.6	69.1	14.7	16.2
Greenfield et al., 1998	retrospective	30	73.8	NA	56.7	26.7	16.7
Jönsson & Strömqvist, 1994	prospective consecutive	50	NA	2	74	23	3
Ragab et al., 2003	retrospective	118	74	NA	92	4	4
Wang et al., 2003	retrospective	88	78.5	NA	leg 43/42; back 43/33	NA	leg 15; back 24
Zheng et al., 2001	retrospective	83	70	3	83	7	10

TABLE 3: Mean rate of reported major complications affecting surgical intervention for elderly patients with deformity

Major Complication	Mean Percentage (range)
dural tear	5.5 (0.4–15)
wound infection	5.25 (1–16)
pulmonary	5 (0.1–11)
renal	4.7 (1–20)
neurological	4.7 (1–11)
gastrointestinal	4.5 (1–8)
cardiac	3.7 (1–13)

or less, for example, was 6 times more likely to improve compared with an initial score higher than 35.[51] A similar trend was observed among the Scoliosis Research Society scale scores; however, there were only a few studies that used this outcome measure. Overall, patients with less initial morbidity, that is, lower ODI and VAS scores, had a decreased chance of improving clinically compared with those with more severe symptoms.

A study by Jönsson and Strömqvist[30] found that in a cohort of surgical patients 70 years of age and older, 74.3% had good or excellent outcomes for lower-back pain and 80.4% had similar results for leg pain. Among patients 80 years and older undergoing laminectomy for spinal stenosis, Galiano et al.[21] noted that at 2.7 years of follow-up, there was a 54.1% improvement in ODI and a statistically significant decrease in analgesic usage.

Elderly patients pose a unique challenge to the spine surgeon. Because their mobility and activities of daily living tend to be affected, the fear of losing their independence is greater than that in younger individuals.[27] This stresses the importance of setting realistic expectations for the patients. Interestingly, a study by Gepstein et al.[22] found that in patients older than 64 years, there was such a correlation between high expectations and satisfaction in those treated for lumbar spinal stenosis that preoperative expectations could be used to predict patient satisfaction.

There is a growing body of literature supporting the use of spinal surgery in the elderly. Arinzon et al.[5] analyzed the surgical management of spinal stenosis in elderly patients in 2 groups. In one group, the patients were between 65 and 74 years of age, and in the other group they were older than 75 years. Patients were treated with decompressive laminectomy or decompressive laminectomy plus discectomy. Both groups showed a significant improvement in their pain and ability to perform activities of daily living. Postoperative complications were also similar among these groups.

Among patients 60 years of age and older receiving instrumented arthrodesis of the lumbosacral spine, 57% reported good or excellent results, 27% reported fair results, and only 17% reported poor or worsening results.[25] Within the entire cohort, 64% reported a decrease in pain and 63% reported improvement in overall function.[25] Perhaps most importantly, 73% of those responding demonstrated at least a 50% improvement in their activities of daily living.[25]

Zheng et al.[62] studied patients with an average age of 70 years undergoing posterior lumbar spinal surgery to treat a variety of degenerative spinal disorders. Using the modified low-back outcome scores, favorable outcomes were observed in 71% of patients. While additional degenerative disorders of the bones and joints predicted lower outcomes, 54% reported excellent outcomes, 29% good, 7% fair, and 10% poor. Interestingly, patient age, body mass index, history of hypertension, smoking status, diabetes, pulmonary disease, diagnosis of degenerative scoliosis, number of levels decompressed, or history of fusion procedure had a significant effect on the modified low-back outcome scores.[62] Benz et al.[7] studied a similar cohort and found no significant relationship between early postoperative complications and preexisting comorbidities. The study also found 60% of patients had an improvement of symptoms and 71% would repeat the surgery.

Spinal surgery has also been demonstrated to be effective among octogenarians.[24,52] Thirty-nine patients at least 80 years of age underwent decompressive surgery for lumbar spinal stenosis. The survival rates were 94%, 80.8%, and 72.7% at 2, 3, and 6 years, respectively.[52] Pain, as measured by the VAS, improved from a score of 8.84 ± 1.91 before surgery to one of 3.6 ± 2.35 at last follow-up. Activities of daily living, as measured by the Barthel Index, also improved from 62.8 ± 11.46 to 77.0 ± 11.9. Furthermore, individuals who cited no limitation in their walking ability increased by 32%, with 76% of all patients reporting satisfaction with the results of their surgery.[52] As expected, minimally invasive lumbar spinal decompression has demonstrated similar efficacy in elderly populations.[45] Among 57 patients with a mean age of 81 years, no major complications or deaths were reported.[45] Mean VAS scores decreased from 5.7 to 2.2 for back pain and from 5.7 to 2.3 for leg pain. In total, 80% reported a decrease in back VAS pain scores. The mean ODI score decreased from 48 to 27, while the mean SF-36 physical function score increased from 26 to 48.[45] No major complications occurred in this study, but patients did report urinary retention (6 patients), transient delirium (5), unintentional durotomy (3), fever (3), urinary tract infection (2), atrial fibrillation (1), constipation (1), and pneumonia (1).[45]

Complications

A search of the broader spine literature regarding age and surgery-related complications yielded the following results. Cloyd et al.[14] found a 10% increase in mortality among individuals 80 years of age and older. The major complication rate was 35% with an OR of 9.2.[42] Among 51 patients 60 years of age and older undergoing spinal deformity reconstructive surgery with a minimum 5-level fusion, 37% were found to have perioperative complications.[15] Twenty percent had at least one major complication such as neurological defect, pulmonary embolism, pneumonia, myocardial infarction, and deep wound infection. Significant factors for complication included age and posterior pedicle subtraction osteotomy. These factors were also associated with additional blood transfusions. Daubs et al.[15] also found that with every year increase in age, the risk of at least one major postoperative complication rose 23%. Furthermore, patients older than 69 years were

shown to be 9 times more likely to have a major complication than those younger than 69 years. Among patients undergoing pedicle subtraction osteotomy, the risk for at least one major complication was increased 7 times.[15]

Cassinelli et al.[13] found that among 166 patients 65 years of age and older undergoing posterior lumbar decompression and fusion with or without instrumentation, only 5 major complications were noted. The authors found that medical comorbidities, advanced age, and the use of instrumentation did not significantly increase the rate of complications, indicating that posterior lumbar decompression and fusion is safe for elderly patients. In fact, the only risk for major complications was the decompression and fusion of 4 or more segments.[13] Similarly, Ragab et al.[43] found that among 118 patients older than 70 years of age undergoing decompressive lumbar surgery, advanced age did not increase morbidity or mortality.

The array of complications associated with spine surgery is diverse.[12,33,53] Interestingly, Best and Sasso[9] recently reported a 1.7% complication rate for decompression among 243 elderly patients, while a similar study by Wang et al.[59] targeted patients 75 years of age and older and reported a complication rate of 33%. A study by Baron and Albert[6] found that 70% of patients who underwent combined anteroposterior fusion had at least one complication, the most common being urinary tract infection. Additionally, 7.8% of patients developed a wound infection.

Pulmonary complications are not uncommon and in some studies are reported to be as high as 64%.[31] The rate of deep vein thrombosis has been shown to vary depending on the surgical approach.[16,44] Dearborn et al.[16] found deep vein thrombosis rates to be 6% for anteroposterior fusions and 0.5% for posterior fusions. Rokito et al.[44] found the rate to be 0.3% among 329 patients undergoing spinal fusion, while West and Anderson[61] found the rate to be 14% among 41 patients undergoing posterior spinal fusion only. Cardiac complications are not very common.[31] Baron and Albert[6] reported that 1.8% of patients developed chest pain and 0.6% developed postoperative arrhythmia. Renal failure has been estimated to occur in 1.2% of all forms of surgery.[11] Gastrointestinal complications are more common. Postoperative ileus was reported in 5%–12% of patients undergoing all spine procedures.[2] Constipation has also been reported but is most likely medication related. A rare, yet potentially life-threatening complication is superior mesenteric artery syndrome, which was found in 0.5% of patients undergoing surgical correction of scoliosis.[6]

DeWald and Stanley[17] found instrumentation-related complications to occur at a rate of 13% in the early postoperative period compared with 4%–32% in the late postoperative period. It is also noted that bone quality is a major factor in surgical success. Early instrumentation complications included epidural hematoma, compression fracture of the most cephalad instrumented vertebral body, and mild compression fracture of adjacent cephalad vertebral body. Late instrumentation complications include pseudarthroses with rod breakage, loosening of pedicle screws at the last instrument level, acute disc herniation, painful instrumentation, progressive junctional kyphosis at the cephalad level, late compression fractures, and progressive kyphosis.[14,17]

Strategies for Complication Avoidance: Preoperative Evaluation

The preoperative evaluation of the elderly patient with spinal deformity is important because surgical morbidity and mortality have been shown to be higher in this population. The patient and the physician need to recognize the age-related factors that contribute to the increase in complications in the elderly.[15] Specifically, the presence of coexistent disease and reduced physiological reserve have largely been proven to affect outcomes in elderly patients.[6,28,39] The mortality rate from myocardial infarction following noncardiac surgery has been estimated to be as high as 70% and has been reported to occur without recognized symptoms in 10% of elderly patients.[36] The respiratory system is a major source of morbidity following deformity surgery. It has been reported that patients older than 70 years without preexisting lung disease have a 40% likelihood of abnormal pulmonary functioning.[6] The elderly patient will more likely have poor renal functioning than any other system pathology.[6,46] These findings can have important implications in the patient peri- and postoperatively because of volume dynamics.[46] Malnutrition is often seen in elderly people; 30%–60% of geriatric patients in hospitals are malnourished.[58] Moreover, some studies have evaluated malnutrition as a possible risk factor for nosocomial infections in those patients.[49] In addition, other studies have reported that malnutrition in elderly surgical patients increases morbidity and mortality.[40] The most common parameters that are used to evaluate the nutritional status are weight or albumin and sometimes bone mineral density.

Osteoporosis Evaluation

Osteoporosis is a complex metabolic disorder characterized by a decrease in bone mineral density that affects approximately 4–6 million women and 1–2 million men in the US.[10] Among the elderly, osteoporosis-related vertebral compression fractures represent the most common spinal fractures in the elderly.[48] Osteoporosis can also contribute to the development and progression of degenerative scoliosis in the elderly, and it is a significant risk factor for hardware instrumentation failure.[14] However, it is important to note that since osteoporotic patients can present with more severe pathologies, they often require more aggressive surgical techniques, thus placing an already susceptible patient at an increased risk.[17]

In a survey of spine surgeons regarding osteoporosis and osteomalacia screening for fractures, fusion surgery, and pseudarthrosis, Dipaola et al.[19] found that a large portion of the spine surgeons, including both orthopedic and neurosurgeons, do not perform routine osteoporosis workups, 60% obtained DEXA scans routinely, and 39% checked metabolic bone laboratory tests. The rates of osteopenia and osteoporosis in patients 50 years of age or older have been reported to be as high as 46% and 31%, respectively. It is therefore suggested that preoperative bone mineral density screening should be done routinely in the elderly population. Different tests have been used. A DEXA scan is a reliable way to assess the bone and determine its mineral content and blood samples for

vitamin D, parathyroid hormone, and calcium levels.[19] From the analyses of Dipaola et al.,[19] it appears that spine surgeons prefer the use of the DEXA scan over a blood workup. Being aware of all risk factors helps to optimize patients' outcomes and surgical planning.

Minimally Invasive Techniques

Minimally invasive spine surgical techniques have recently been used in the context of adult spinal deformity.[4] Considering that adult spinal deformity surgery has been associated with blood loss ranging from 360 to 7000 ml for instrumented fusions, deformity surgery may be prohibitive in the elderly.[38] It has been argued that given the relatively high complication rates associated with surgery for lumbar scoliosis (56%–75%) and the high unplanned reoperation rates (18%–58%), and that given the theoretically higher complication rates associated with advanced age and increasing medical comorbidities, the decision to perform surgery in the elderly patient with spinal deformity must be made very carefully.[1] The case may be made against operative treatment in this group or for only short segment intervention.[1,60]

Minimally invasive spine surgery techniques have evolved to the point to which they may be useful for the correction of deformity. They are associated with significantly less blood loss than open procedures (when compared with historical controls).[4] When compared with open procedures, they also may result in reduced muscle damage, reduced postoperative pain medication requirements, and reduced muscle dysfunction.[4,56] In the past, minimally invasive anterior approaches were considered "technically demanding" and theoretically associated with longer operative times. Nevertheless, as experience has increased with techniques such as the lateral transpsoas approach for discectomy and fusion and the percutaneous, presacral approach for discectomy and fusion, operative times have been demonstrated that are certainly comparable to open techniques.[4] Newer percutaneous unconstrained pedicle screw systems that use freehand rod passage and appropriate contouring of the rod allow for minimally invasive multisegment fixation. In summary, minimally invasive deformity correction seems clearly preferable considering the reduced blood loss and acceptable operative times when compared with traditional open approaches. This may be particularly advantageous in the elderly and other populations with coexisting medical comorbidities.

Conclusions

As life expectancy increases and the population continues to age, the number of elderly patients seeking surgical correction of scoliosis is expected to increase. Adult spinal deformity surgery should not be regarded as a "cure." Most elderly patients obtained favorable outcomes with low operative mortality following spinal surgery.

It is important to clearly understand the risk factors and complications for this population to optimize patient outcomes. Complications can be decreased with a thorough presurgical evaluation, assessment of the presence of osteoporosis, and comprehensive preoperative and postsurgical medical management. Minimally invasive techniques and early mobilization should be considered.

Future clinical trials should be conducted to answer the question about whether minimally invasive versus open correction is the best option for this population. Clinical studies with long-term follow-up need to be conducted to assess the best way to manage surgical complications and strategies to avoid these complications.

Disclosure

Dr. Acosta is a consultant for Stryker Spine.

Author contributions to the study and manuscript preparation include the following. Conception and design: Drazin. Acquisition of data: Drazin, Safee. Analysis and interpretation of data: Shirzadi, Rosner. Drafting the article: Drazin, Shirzadi, Rosner, Eboli, Safee, Baron. Critically revising the article: Acosta, Drazin, Shirzadi, Eboli, Liu. Reviewed submitted version of manuscript: Acosta, Drazin, Shirzadi, Safee, Liu. Administrative/technical/material support: Rosner. Study supervision: Acosta, Shirzadi, Liu.

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Manuscript submitted June 15, 2011.
Accepted July 27, 2011.

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Neurosurg Focus 31 (4):E4, 2011

Minimally invasive lateral lumbar interbody fusion and transpsoas approach–related morbidity

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Object. Recently, the minimally invasive, lateral retroperitoneal, transpsoas approach to the thoracolumbar spinal column has been described by various authors. This is known as the minimally invasive lateral lumbar interbody fusion. The purpose of this study is to elucidate the approach-related morbidity associated with the minimally invasive transpsoas approach to the lumbar spine. To date, there have been only a couple of reports regarding the morbidity of the transpsoas muscle approach.

Methods. A nonrandomized, prospective study utilizing a self-reported patient questionnaire was conducted between January 2006 and June 2008 at Northwestern University. Data were collected in 53 patients with a follow-up period ranging from 6 months to 3.5 years. Only 2 patients were lost to follow-up.

Results. Thirty-six percent (19 of 53) of patients reported subjective hip flexor weakness, 25% (13 of 53) anterior thigh numbness, and 23% (12 of 53) anterior thigh pain. However, 84% of the 19 patients reported complete resolution of their subjective hip flexor weakness by 6 months, and most experienced improved strength by 8 weeks. Of those reporting anterior thigh numbness and pain, 69% and 75% improved to their baseline function by the 6-month follow-up evaluations, respectively. All patients with self-reported subjective hip flexor weakness underwent examinations during subsequent clinic visits after surgery; however, these examinations did not confirm a motor deficit less than Grade 5. Subset analysis showed that the L3–4 and L4–5 levels were most often affected.

Conclusions. The minimally invasive, transpsoas muscle approach to the lumbar spine has a number of advantages. The data show that a percentage of the patients undergoing the transpsoas approach will have temporary sensory and motor symptoms related to this approach. The majority of the symptoms are thought to be related to psoas muscle inflammation and/or stretch injury to the genitofemoral nerve due to the surgical corridor traversed during the operation. No major injuries to the lumbar plexus were encountered. It is important to educate patients prior to surgery of the possibility of these largely transient symptoms. *(DOI: 10.3171/2011.7.FOCUS11137)*

Key Words • **lateral lumbar interbody fusion** • **transpsoas approach** • **direct lateral approach** • **extreme lateral approach** • **minimally invasive approach**

The history of modern spinal surgery dates back almost 100 years. Many of the first applications of spinal surgery were directed toward treating infections of the spinal column.[1] Traditionally, these surgeries are performed with open anterior and posterior approaches to the spine, requiring large incisions for adequate exposure. In the early 1990s, a new field was on the horizon, which provided more direct access to the regions of pathology. The first reports of minimally invasive spine surgery appeared in 1991 when Obenchain[16] described a laparoscopic lumbar discectomy. Since that time, the art of minimally invasive spine surgery has become more refined and more popular.[23] The advantages include less tissue disruption, less postoperative pain, shorter hospital stays, and faster return to normal activities.[19,20]

Abbreviations used in this paper: ALIF = anterior lumbar interbody fusion; DLIF = direct lateral interbody fusion; GFN = genitofemoral nerve; LLIF = lateral lumbar interbody fusion.

The aim of this study is to evaluate the morbidity of the transpsoas approach. This approach differs from the previous retroperitoneal approaches in that the access to the spine is directly through the iliopsoas muscle via a much shorter incision, versus a larger exposure and subsequent retraction of the psoas in the posterior direction.

Methods

A nonrandomized, prospective study utilizing a self-reported patient questionnaire was conducted between January 2006 and June 2008 at Northwestern University. Following institutional review board approval, data were collected in 53 patients in the study with a follow-up period ranging from 6 months to 3.5 years (mean 21.2 months). Self-reported questionnaire data were collected in 53 patients, of whom 2 were lost to follow-up. Any patient who reported new symptoms after surgery on the questionnaires was monitored either in the clinic or by telephone.

Our surgical technique varies slightly from the original description of the lateral retroperitoneal approach. Briefly, following general endotracheal anesthesia, patients are positioned in the lateral decubitus position, with the left or right side upward depending on local anatomy (degenerative lumbar curves, coronal imbalance, and so on). The upper leg is flexed at the hip to allow for psoas relaxation, and the patient is secured in place with all pressure points adequately padded. The bed is adjusted to obtain true anteroposterior and lateral images, while the C-arm radiography unit is maintained at perfect right angles (locked at 0° and 90°). In patients treated in the most recent 2 years, the O-arm was used with navigation during the procedure, thus minimizing radiation exposure to the surgeon and operating room staff. We use a single 3–4-cm incision with the DLIF (Medtronic) technique. With the use of finger dissection, serial tubular dilators are placed through the psoas muscle, and a single anchoring screw for the dual-bladed retractor. Once in position, visual inspection is made of the GFN and lumbar plexus. Additionally, electromyography testing confirms the absence or presence of such structures. Care is taken to stay on the anterior half the vertebral body to avoid the lumbar plexus, which anatomically lies posterior.[8,15] We also traverse the contralateral anulus to ensure the interbody graph spans both edges of the vertebral body. Interbody cages with beveled edges, filled with Infuse (recombinant human bone morphogenetic protein (rhBMP-2) (Medtronic), are directed into place under fluoroscopy or monitored with O-arm navigation. Of note, rhBMP-2 is FDA approved for anterior interbody fusion. However, we routinely inform and obtain consent from patients for the off-label use in the LLIF procedure.

Specific approach-related questionnaires were given in the immediate (0–8 weeks) and long-term follow-up periods. If patients reported yes to any of the questions they were monitored for longer time periods. The following questions were asked. 1) On the side you had surgery, did you have new weakness in that leg following surgery? (Particularly, when flexing the hip or lifting your entire leg?) 2) On the side you had surgery, did you have new pain in leg following surgery? (Specifically, in the front of your thigh/groin?) 3) On the side you had surgery, did you have new numbness in leg following surgery? (Specifically, in the front of your thigh/groin?)

Each question specified whether the symptoms were persistent or resolved. Also, the duration and severity of symptoms were quantified. An additional question asked if an abdominal wall hernia developed at the site of surgery. Complete follow-up, including questionnaires and physical examinations in the clinic setting, was obtained in 53 patients (102 levels). Of the 102 total levels, 22 were single-level cases treated with DLIF, and 31 were multilevel cases.

The primary objectives were to evaluate 1) transpsoas muscle edema causing hip flexor weakness; 2) GFN irritation causing numbness and/or pain; and 3) lumbar plexus/nerve root injury.

Results

Thirty-six percent (19 of 53) of patients experienced some transpsoas approach–related symptoms including subjective hip flexor weakness, and 84% reported complete resolution by 6 months, most of which were resolved by 2 months. Only 1 patient reported symptoms after 2 years, although clinical testing did not confirm the patient's complaints. Twenty-five percent (13 of 53) reported new thigh/groin numbness on the side of surgery; 69% of these patients reported returning to normal by 6 months after surgery, the majority of whom reported taking most of that time to recover. Twenty-three percent of patients reported new thigh/groin pain, and 75% of these patients reported resolution of their pain by 6 months. These patients experienced this pain for a shorter time than those who reported sensory loss. One patient reported very mild persistent numbness and pain in the groin 1 year after surgery. There were no nerve root/lumbar plexus injuries.

A subset analysis of the single-level operations was performed. Thirty-three percent (3 of 9) of patients undergoing procedures at L3–4 and 57% (4 of 7) of those undergoing procedures L4–5 reported hip flexor weakness. Twenty-five percent (1 of 4) of patients undergoing procedures at L2–3 reported hip flexor weakness; none of those undergoing procedures at the L1–2 and T12–L1 levels reported this weakness. Thirty-nine percent (12 of 31) of patients undergoing multilevel procedures reported hip flexor weakness. The difference between levels did not reach statistical significance using logistic regression analysis (weakness $p = 0.24$, pain $p = 0.82$, and numbness $p = 0.27$). There were no vascular injuries. One patient experienced a psoas hematoma requiring transfusion, but reoperation was not required. In 1 case, the segmental artery was lacerated, which was successfully repaired with bipolar electrocautery.

Discussion

The advances in minimally invasive techniques have surfaced in anterior and posterior approaches. In the mid-1990s, there were several reports of ALIFs that used a laparoscopic approach.[5,24] These primarily targeted the L5–S1 and L4–5 disc spaces. Wide use and acceptance of the laparoscopic ALIF was deterred by the known challenges and complications of laparoscopic spine surgery. Reports of retrograde ejaculation,[4,7] vascular injury,[2] anesthetic complications,[9] need for an access surgeon, and steep learning curve all limited the popularity of this procedure.[13]

The retroperitoneal approach to the lumbar spine was first reported by Harmon[10] in 1963. This surgical trajectory takes advantage of a natural corridor in the retroperitoneal space that leads to the lateral aspect of the spine. Mayer and Wiechert[14] described a "minimally invasive retroperitoneal approach" where the length of incision could be drastically shortened as the surgeon gains more experience. Saraph et al.[22] compared the traditional open approach described by Harmon with the minimally invasive approach of Mayer and Wiechert and showed less blood loss and shorter hospital stays and described shorter incisions. The minimally invasive length of incision ranged from 6 to 20 cm versus the traditional approximately 50-cm-long incisions that a general surgeon would

use to access the spine. These authors reported no statistical difference with respect to standard complications. They reported that 5 (9%) of 56 patients suffered injury to the lateral femoral cutaneous nerve. It is important to note that in this approach, the psoas muscle is retracted posteriorly.

The endoscopic retroperitoneal approach to the spine had also been used in the past. Bergey et al.[3] reported a series of 21 patients who underwent an endoscopic, lateral retroperitoneal, transpsoas approach to the anterior spine for interbody fusion. This was the first report of a transpsoas approach to the spine. These authors discussed the anatomical considerations of the approach, as well as their experience with approach-related morbidity. They reported an average surgical time of 149 minutes and a mean hospital stay of 4.1 days.[3] They used the following 4 ports: a working port (1 cm), a suction port (0.5 cm), a laparoscopic port (1 cm), and a psoas retractor port (1 cm). The total incision was approximately 3.5–4 cm. The authors used BAK cages in the interbody space with autograph. They reported that 6 patients (30%) developed transient postoperative groin/thigh paresthesias. Also, 5 (27%) of these patients complained of groin/thigh pain. The authors did not mention whether any of the patients had postoperative hip flexion weakness. Groin/thigh pain in 2 patients persisted beyond 1 month. In 1 of these patients, there was persistent pain in his anterior thigh 11 months after surgery, which was treated with Neurontin. The authors concluded that their approach is safe, with some patients experiencing symptoms related to the transpsoas corridor.

Ozgur et al.[18] described, in a step-wise manner, the eXtreme Lateral Interbody Fusion (XLIF) (NuVasive, Inc.), which is a minimally invasive, lateral retroperitoneal, transpsoas approach to the anterior spine for interbody fusion. A 2-incision technique was described for the approach, with an anchorless 3-blade retractor, and early clinical results were discussed.[18] The first incision was 3–4 cm, with a second more posterior incision of about 2 cm.[18] In the 13 patient series, all were supplemented with posterior percutaneous pedicle fixation, and the authors reported an average 45 minutes per level surgical time. The authors reported no complications in their first 13 patients.

Recently, Knight et al.[12] reported a series of 58 patients who underwent a DLIF or XLIF minimally invasive, lateral retroperitoneal, transpsoas approach to the spine. The authors focused on mild or major adverse events during hospital stay or within 6 weeks of discharge and reviewed the charts. They reported that adverse events occurred in 18 of 58 patients, and 13 of 58 had major or mild complications. Nine complications were approach-related: there were 2 cases of ipsilateral L-4 nerve root injury, 6 cases of irritation of lateral femoral cutaneous nerve resulting in meralgia paresthetica, and 1 case of significant psoas muscle spasm leading to an extended hospital stay. The authors did not mention any significant transpsoas weakness in their complication profile. They concluded that DLIF techniques have proven to be of value in management of lumbar degenerative conditions.[12]

There are several published papers and abstracts that describe morbidity of the minimally invasive lateral lumbar interbody fusion, but most do not specifically focus on transpsoas muscle morbidity.[11,21] In our experience, there are 3 primary symptoms associated with the transpsoas approach, including thigh and/or groin pain and numbness, as well as hip flexion weakness. These symptoms are most often temporary and resolve within 2 months. Initial findings were elicited on postoperative motor and sensory examinations while patients were still in the hospital, and they were not due to patients explicitly complaining of weakness, numbness, or pain in the thigh/groin area. It is important to mention that only a few of these patients volunteered the information in the postoperative setting. This might indicate that the signs and symptoms were mild and not affecting the patient's overall functional status or well being. The patients who reported weakness on the questionnaire were examined and found to have full motor function on physical examination.

Hip flexion weakness is likely due to splitting the psoas muscle. It is theorized that the muscle undergoes a postoperative edematous reaction, which contributes to the dysfunction. The more cephalad disc spaces do not have as much psoas muscle over the lateral body wall, so at L2–3 and above, transpsoas muscle weakness is rarely an issue. Thirty-six percent of the patients reported these symptoms; 50% of them had resolution of their weakness by 2 months, and 84% were normal by 6 months. One patient reported persistent symptoms at 2 years; however, this was not reflected in gait and could not be detected on physical examination.

The thigh/groin pain and numbness are likely due to manipulation of the GFN. The GFN arises from L1–2 roots and passes obliquely through the substance of the psoas. It emerges at the L3–4 level on the anterior surface of the psoas muscle and travels inferiorly covered by the peritoneum to divide into the genital and femoral branches. Symptoms most frequently include medial thigh and groin pain and/or numbness; 23% and 25% of patients, respectively, reported these symptoms. There are no reliable electrodiagnostic tests that can be used for diagnosis of injury to this nerve. Upon the initial surgical approach, careful inspection of the muscle at these levels may avoid excessive manipulation of the GFN. As one would expect, our study showed that these symptoms took longer to recover than the symptoms of hip flexor weakness, with pain resolving first followed by the sensory deficit. Fifty percent of those experiencing thigh and/or groin pain had resolution by 2 months, and a total of 75% resolved by 6 months. In contrast, 15% of patients reporting numbness had resolution by 2 months, and 69% had resolution by 6 months. Patients who reported dysesthetic pain were treated with Neurontin or pregabalin; this medical therapy conferred pain relief to varying degrees. The medications were gradually tapered as the symptoms resolved. One patient reported that numbness and pain that lasted longer than 1 year, although the symptoms at 1 year were mild and did not require medication.

We encountered no lumbar plexus or nerve root injuries. Since the upper lumbar plexus innervates the iliopsoas muscle, one could contest that an injury to the upper lumbar plexus could not be distinguished from the transpsoas weakness due to muscle swelling. Also, injury

to the upper plexus (L1–2 nerve roots) could cause some of the symptoms associated with GFN irritation. We acknowledge this to be a possibility; however, we would expect other neurological findings referable to the L-1 or L-2 nerve roots. A recent report evaluated other peripheral nervous structures at risk during the lateral approach to the lumbar spine.[6] This cadaveric study nicely characterized the main motor and sensory branches of the lumbar plexus outside the psoas muscle. They identified 4 other nerves at risk: the subcostal, iliohypogastric, ilioinguinal, and lateral femoral cutaneous nerves. In addition to the commonly encountered GFN, the authors appropriately concluded that the surgeon should be aware of other potential nerve palsies in the postoperative period. In our series, there was no reason to suspect injury to these other peripheral nervous structures.

The advantages of LLIF over ALIF (mini-open or laparoscopic) include avoidance of the hypogastric plexus, thus avoiding risk of retrograde ejaculation.[4,7] Furthermore, the great vessels are much less a threat to the surgeon than in the anterior approach, as evidenced by incidence of injury.[2,22] In our experience and that reported by Knight et al.,[12] there were no major vascular complications in a combined total of 113 patients. These advantages are recognized when working at the L4–5 level. The anterior approach can be used to visualize the L5–S1 interbody space, but the direct lateral approach cannot be used at this level given the presence of the iliac crest. Some patients may have an anatomically unfavorable pelvis and the L4–5 may not be accessible via LLIF approach as well. Endoscopic transiliac access to the L5–S1 disc has been performed in cadavers;[17] however, to our knowledge this has not been attempted in patients. Also, the lumbar plexus is anatomically most anterior along the vertebral body wall at this level,[14] posing a theoretically larger risk for nerve root injury.

Conclusions

The minimally invasive, lateral retroperitoneal, transpsoas approach to the anterior spine is a viable and safe option for accessing the interbody space. The morbidity of the transpsoas approach can be divided into the following 3 categories: 1) transpsoas swelling causing hip flexor weakness, 2) GFN irritation causing numbness and/or pain of the thigh/groin area, and 3) lumbar plexus/nerve root injury. Patients did not typically complain of these symptoms; rahter, they were discovered during the investigation, which is possibly an indication of their severity. Preoperatively, patients undergoing this specific approach should be warned of the possibility of hip flexor weakness due to psoas swelling and the possibility of a transient thigh/groin numbness and pain due to GFN irritation in addition to the standard preoperative discussion. Patients can be reassured that most of these symptoms will resolve with time if they do experience them.

Complication avoidance is of paramount import, and there are several key steps that minimize morbidity. As mentioned in *Methods*, once the final tube is secured in position, we directly visualize the psoas muscle. This ensures that there are no nerves crossing the surgical corridor, especially the commonly encountered GFN. Perhaps the greatest impact on postoperative psoas-related morbidity involves the extent of psoas muscle dilation. Over the years, one of the senior authors (J.C.L.) has modified the technique such that the psoas muscle is no longer traversed with the dilators. Instead, the tubes are docked to rest on the psoas. Using a Penfield No. 4 dissector, the psoas is carefully and bluntly dissected in an atraumatic fashion. Theoretically, this maneuver might lead to less muscle tissue trauma and therefore result in less postoperative psoas-related morbidity. The clinical results of this variant in surgical technique are currently under review with anticipated future publication.

Disclosure

Dr. Fessler received support of non–study-related clinical or research effort from Medtronic. Dr. Liu is a consultant for Medtronic.

Author contributions to the study and manuscript preparation include the following. Conception and design: all authors. Acquisition of data: Moller. Analysis and interpretation of data: Moller, Liu. Drafting the article: Slimack, Moller. Critically revising the article: Slimack, Moller, Liu. Reviewed submitted version of manuscript: Slimack, Moller, Liu. Approved the final version of the manuscript on behalf of all authors: Slimack. Statistical analysis: Moller.

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Manuscript submitted June 15, 2011.
Accepted July 14, 2011.

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Neurosurg Focus 31 (4):E5, 2011

Strategies to avoid wrong-site surgery during spinal procedures

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Wrong-site surgery (WSS) is a rare occurrence that can have devastating consequences for patient care. There are several factors inherent to spine surgery that increase the risk of WSS compared with other types of surgery. Not only can a surgeon potentially operate on the wrong side of the spine or the wrong level, but there are unique issues related to spinal localization that can be challenging for even the most experienced clinicians. The following review discusses important issues that can help prevent WSS during spinal procedures. *(DOI: 10.3171/2011.7.FOCUS1166)*

Key Words • **wrong-site surgery** • **"time-out" process** • **spinal localization** • **medical malpractice** • **complication**

Wrong-site surgery is a rare occurrence that can have devastating consequences for patient care. In a survey of members of the American Academy of Neurological Surgeons performed by Mody et al.,[13] 50% of responding surgeons reported that they had performed at least 1 wrong-level surgery during their career. Of 418 wrong-level surgeries, 17% resulted in litigation or monetary settlement. The WSS can take many forms, including surgical intervention at the incorrect location, performing the wrong procedure on a patient, or operating on the wrong patient altogether. Although the incidence of WSS is likely to be extremely low,[7] a zero-tolerance policy should be promoted by health care institutions to ensure that all possible precautions are instituted to prevent such an occurrence. Vigilance against WSS should be particularly high for spine surgeons, because there are several factors inherent to spine surgery that increase the risk of WSS compared with other types of surgery. Not only can a surgeon potentially operate on the wrong side of the spine or the wrong level, but there are unique issues related to spinal localization that can be challenging for even the most experienced clinicians. The following review discusses important issues that can help prevent WSS during spinal procedures.

Abbreviations used in this paper: NASS = North American Spine Society; PMMA = polymethylmethacrylate; VB = vertebral body; WSS = wrong-site surgery.

Preoperative Verification of Surgery

An important strategy to prevent WSS involves using a preoperative checklist of procedures and points of discussion designed to ensure that the intended operation is being performed on the correct patient. Both the NASS[15] and the Joint Commission[9] have developed guidelines designed to foster communication among the surgical team, anesthesiologist, nursing staff, and the patient. Both organizations suggest that all members of the clinical staff, as well as the patient, should be involved in marking the site of surgery. Involvement of the patient helps to ensure that everyone understands the surgery to be performed, and it allows the clinical team to confirm that the intended surgery coincides with the patient's symptomatology (that is, a left-sided discectomy for left-sided radicular pain). The Joint Commission guidelines further recommend that a formal "time-out" process be performed immediately before making incision. The time-out procedure should include discussion of the patient's identity, site of surgery, and procedure to be performed. Intraoperative localization of the exact spinal levels of interest is suggested, but not mandated by either set of guidelines.

It is important to acknowledge that even a strict adherence to guidelines proposed by the Joint Commission or NASS will not prevent all instances of WSS during spinal procedures. In a review of 13 nonspine WSSs identified in a health insurance administrative database, Kwaan

and colleagues[10] concluded that the Joint Commission guidelines would not have prevented 5 cases (38%). Because of the challenges unique to spine surgery localization, adherence to Joint Commission or NASS guidelines may fail to prevent an even higher number of WSSs for patients undergoing spine surgery. It is clear that preoperative checklists should be only 1 component of an overall strategy to prevent WSS in spinal procedures.

Intraoperative Localization

Accurate and efficient intraoperative localization of spinal lesions is critical to patient safety and maximizing clinical outcomes. This task is especially challenging in certain clinical situations, including operations in morbidly obese patients, those with pathological entities in the thoracic spine, and patients with variations in spinal anatomy. Failure to anticipate such issues preoperatively can lead to prolonged localization time during the operation or to WSS. The following discussion highlights common pitfalls in spinal localization and reviews current techniques that can be used to expedite spinal localization and prevent WSS.

Localization in the Cervical Spine

Accurate spinal localization can be successfully achieved using a combination of anatomical landmarks, clinical correlation (the presence of fractures, instability, and so on), and intraoperative radiological studies. Although sole dependence on 1 of these 3 strategies usually leads to successful localization, multiple strategies should be used to ensure the prevention of WSS. Anatomical landmarks are easily identifiable in the cervical spine of most patients. The large C-2 spinous process can be used for localization in the upper cervical spine, whereas T-1 (with a large lamina and transverse process that articulates with the first rib laterally, a significant contrast compared with the small lateral mass of C-7 that does not articulate with a rib) can be used to localize levels in the lower cervical spine.

For the majority of patients with normal body habitus, plain radiographs or fluoroscopy provide adequate resolution for localization in the cervical spine. For patients with a large body habitus or short neck, visualization of the lower cervical spine can be challenging. Even with caudal traction of the shoulders performed using tape, it may be impossible to obtain adequate imaging of the lower cervical spine. This challenge is typically surmounted by affixing an instrument into a fixed structure in the upper cervical spine that can be visualized radiographically and "counting downward" to deduce the level of interest. This technique typically yields satisfactory results but may require unneeded exposure of the upper cervical spine.

One anomaly of the cervical spine that can potentially lead to WSS is a fused spinal level in a patient with Klippel-Feil syndrome, defined as congenital fusion of any 2 cervical vertebrae. A particularly confusing scenario involves patients with fusion of the C-2 and C-3 vertebrae (Fig. 1). In such a situation, the C-3 vertebrae can easily be mistaken for the dens of C-2 on radiographic imaging. Furthermore, the spinous processes of C-2 and C-3 are often fused and difficult to distinguish intraoperatively, thereby further increasing the risk of WSS. Early recognition and due diligence intraoperatively can prevent an unsatisfactory outcome in such a situation.

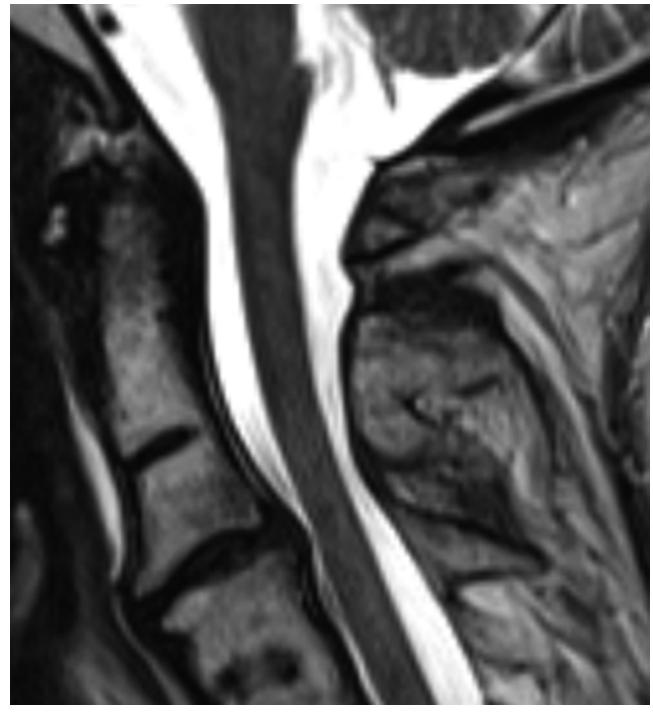


Fig. 1. Sagittal T2-weighted MR imaging study demonstrating fusion of C2–3 VBs and spinous processes.

Localization in the Thoracic Spine

As with localization in the cervical spine, plain radiographs or fluoroscopy usually provide adequate resolution for localization in the thoracic spine. In some individuals, a combination of such factors as a patient's size, scapular shadows, and decreased bone density (for example, patients with osteoporosis) makes accurate intraoperative visualization of the bone anatomy difficult with standard radiographs or fluoroscopy. Even in a best-case scenario, when the patient is thin with normal bone density, care must be taken when localizing lesions in the midthoracic spine. When using plain radiographs, it is not uncommon to require multiple studies, with a marker (e.g., spinal needle) placed at a fixed point on the spine to count from C-2 or the sacrum to the level of interest (Fig. 2). If the practitioner is not careful, incorrect identification of a spinal level is a potential hazard. Real-time fluoroscopic imaging is another localization option, but care must be taken to limit radiation exposure to both the patient and the clinical staff.

When using radiographs or fluoroscopy for midthoracic to low thoracic spine localization, it is often easier to count up from the sacrum to the level of interest instead of caudally from the occiput. The surgeon must keep in mind that the level of the lesion may be described by the radiologist by counting from the occiput downward. In rare situations in which there are 4 or 6 lumbar vertebrae, counting from the sacrum upward would lead to localization at the wrong level (Fig. 3). To prevent such an occur-

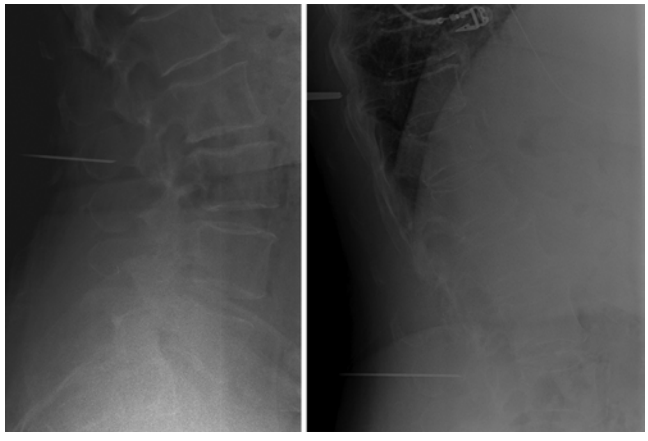


Fig. 2. Localization of the T-10 VB on serial radiographs. **Left:** Initial radiograph clearly visualizing the sacrum, demonstrating that a spinal needle is directed at the L-3 pedicle. **Right:** A second radiograph visualizing the same spinal needle seen in the first study, as well as a clamp affixed to the T-10 lamina.

rence, preoperative imaging should include both the level of interest and the entire lumbar spine when a surgeon anticipates the need to count from the sacrum upward. In addition, the surgeon should use the same counting technique (either rostral or caudal) on both preoperative and intraoperative imaging to avoid this complication.

To expedite localization in the thoracic spine, there are a number of strategies that have been described that may potentially help to avoid WSS. For example, radiopaque skin markers can be placed prior to an MR imaging study or CT scan to localize spinal lesions intraoperatively.[17] This technique may be subject to significant localization error, because the skin and underlying subcutaneous tissues of patients may undergo dramatic shifting and/or folding during positioning. Resulting errors in localization can be dramatic, particularly in obese patients.[16]

In patients undergoing operative procedures in the high thoracic spine, the use of methylene blue dye has been described to mark the spinous process of interest.[16] An anteroposterior radiograph is used to localize the spinous process preoperatively by visualizing dye injected with a 22-gauge needle into the tissue surrounding the relevant spinous process. Although potentially useful for posterior approaches to the thoracic spine, it is not feasible for anterior surgical techniques. In addition, because this dye may be neurotoxic, it must be administered superficially over the posterior spinal elements to avoid inadvertent injection into the spinal canal. Unfortunately, such superficial placement may fail to localize the level with sufficient specificity, because the dye may spread over more than 1 spinous process before surgical exposure can be accomplished.

A novel fluoroscopic technique for thoracic spine localization has recently been described.[19] Instead of depending on true lateral fluoroscopic images that may be inadequate for visualization of the cervicothoracic junction in patients with large body habitus, the fluoroscope is rotated so that the lamina is visualized en face. The resulting oblique fluoroscopic view avoids much of the chest and shoulder mass, thus resulting in a clearer image. Patients undergoing a procedure in which they are placed

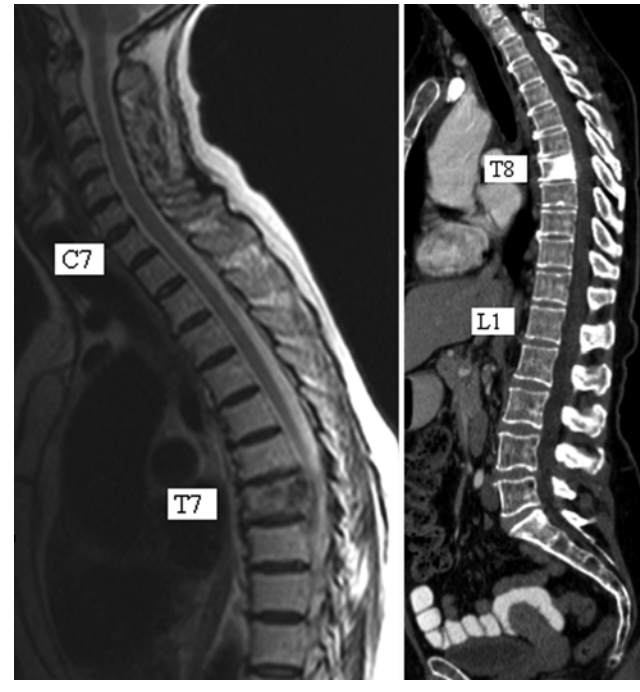


Fig. 3. Left: Sagittal T2-weighted MR imaging study demonstrating a lesion involving a VB. When counting caudally from C-2, the entity was described as a T-7 lesion. **Right:** Sagittal CT scan obtained in the same patient demonstrating that when counting cephalad from the sacrum, the same lesion would be described as involving the T-8 VB.

prone are ideally situated for such a technique. However, in patients with osteoporosis or those undergoing procedures in a lateral decubitus position (that is, thoracotomy), this technique may not be sufficient.

Preoperative vertebroplasty has been used for thoracic spine localization.[8] Unlike the techniques outlined above, this procedure can be used during anterior approaches to the thoracic spine. For this procedure, PMMA impregnated with barium sulfate is clearly visible on radiographs or fluoroscopic studies, thus facilitating the planning of the initial incision and verifying the correct thoracic level of interest intraoperatively (Fig. 4). Injection of PMMA into a VB under fluoroscopy is generally a safe procedure. However, reported complications include radiculopathy,[6] infection,[14] pulmonary fat emboli,[4] pulmonary cement emboli,[2,12] anaphylaxis,[11] pneumothorax, and epidural extrusion with spinal cord compression.[18] However, the overall risk of serious complications from this procedure is low. Chiras et al.[5] reported a complication rate of 1.3% in osteoporotic compression fractures treated with vertebroplasty, but noted higher complication rates in more destructive bone lesions such as hemangiomas (2.5%) and vertebral malignancies (10%). Because the use of vertebroplasty for spine localization involves the injection of only small amounts of PMMA into a relatively normal VB, it is unclear if this technique harbors the same level of risk compared with vertebroplasty for the treatment of vertebral lesions.

Radiopaque coils have been described for the purpose of thoracic spine localization.[3] Using biplanar fluoroscopy, detachable coils are deposited through a needle adjacent to the pedicle of interest. These coils are easily visualized using standard radiographic techniques. Although this pro-

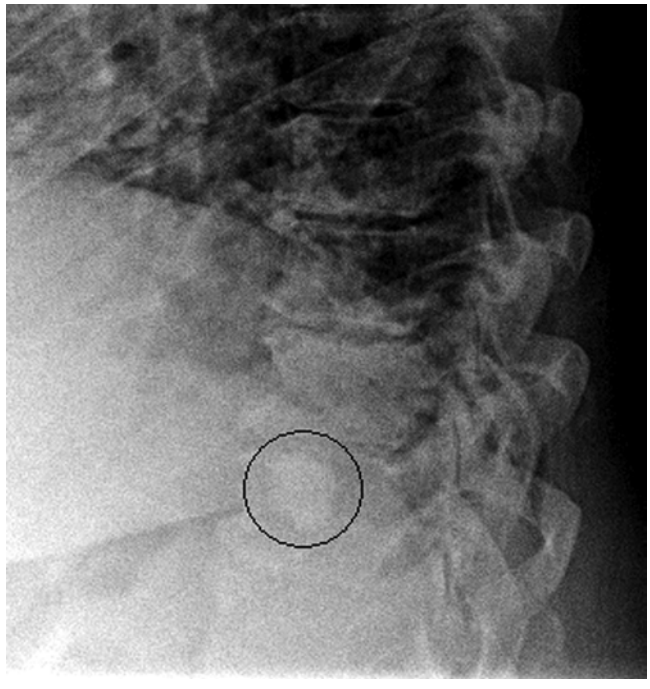


Fig. 4. Intraoperative radiograph obtained in a patient with a T6–7 disc herniation. Cement was injected preoperatively into the T-7 VB *(circle)* to facilitate intraoperative localization.

cedure carries the potential risk of infection, this technique does not carry the risks associated with vertebroplasty and does not disturb the VB of interest.

Localization in the Lumbar Spine

The localization of spinal lesions is generally straightforward in the lumbar spine, but rare instances of WSS in this location can occur without appropriate due diligence. It is critical that, when appropriate, the side of surgery is explicitly verified by the patient, surgeon, and clinical staff before the patient is intubated. Such a process adds another safeguard to prevent WSS, particularly in patients suffering from radicular pain caused by a disc herniation. The patient's preoperative imaging should be available in the operating room for verification that the correct level is being addressed, and these studies can be compared with any images obtained intraoperatively.

There are multiple strategies that can be used to localize the correct level in the lumbar spine. The placement of a clamp on a spinous process or a curette under a lamina followed by a lateral radiograph are commonly used techniques, but these strategies may occasionally lead to unnecessary confusion during the interpretation of the resultant radiograph. We prefer placing a clamp on the transverse process (which is always lateral to the lumbar pedicle) before taking a lateral radiograph. The resulting radiograph always clearly shows a marker adjacent to a pedicle. The levels of interest can then be surmised based on this radiograph.

The use of a spinal needle or other marking method in conjunction with radiographic imaging to plan the initial incision is a common practice in lumbar spine surgery, particularly in cases in which only a small skin incision is necessary to provide lumbar spine exposure appropriate for the procedure of interest (such as lumbar discectomy) (Fig. 5A). In the vast majority of cases, this technique can be used to localize the level of interest accurately. However, it would be a mistake to depend only on this image for the purposes of spinal imaging. For lumbar discectomy, exposure of the wrong lumbar level before commencement of discectomy is a common occurrence,[1] and failure to obtain further imaging intraoperatively before proceeding with the discectomy may potentially increase the risk of WSS. To prevent WSS during lumbar spine discectomy surgery, we routinely obtain 2 radiographic images in addition to any images obtained before skin in-

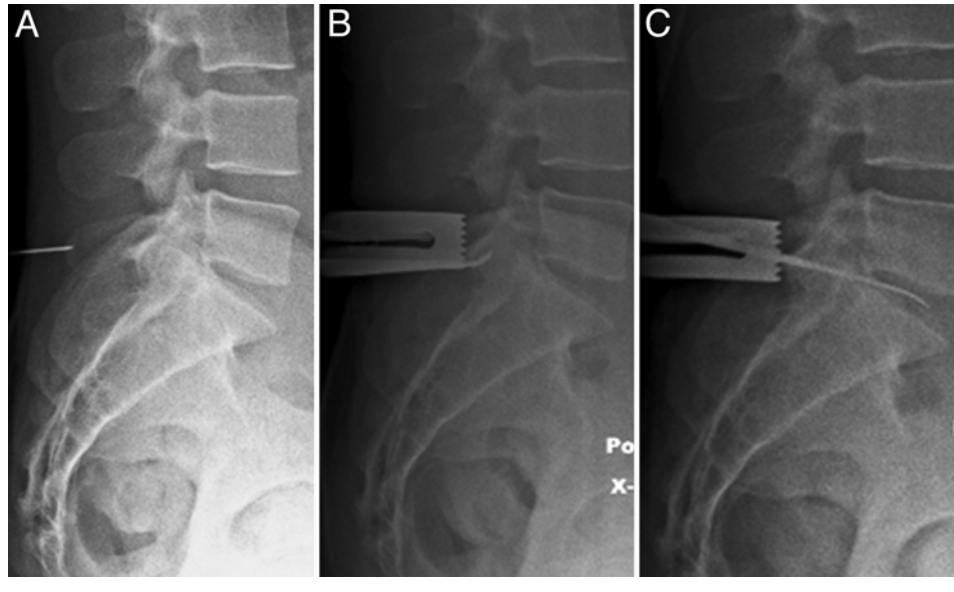


Fig. 5. A: Preincision radiograph obtained to facilitate planning for an L5–S1 discectomy. A spinal needle demonstrates the location of the L-5 spinous process. **B:** Intraoperative radiograph demonstrating a curette hooked beneath the L-5 lamina. **C:** Radiograph demonstrating correct localization of the L5–S1 disc space.

cision (Fig. 5B and C). The first image requires that a radiopaque marker (that is, a metallic clamp) be applied to a fixed structure on the spine to confirm that the marked level is indeed the level of surgical interest. The second image involves placement of a radiopaque marker into the disc space to reconfirm that the exposed disc is the correct level.

Prevention of WSS Using 3D Intraoperative Imaging

Intraoperative 3D imaging is used by many spine surgeons during routine and complex spinal surgery. The vast majority of the literature on this subject focuses on improving the accuracy of instrumentation placement relative to freehand or 2D fluoroscopic techniques. One advantage of 3D intraoperative imaging that is not often discussed is the accurate localization of the correct spinal level of interest. Real-time 3D imaging may be particularly useful during repeat lumbar spine surgery. Patients with a prior fusion surgery in whom a large bony fusion mass develops may lack classic anatomical landmarks, which can make spinal localization difficult. Although we do not advocate the use of 3D imaging techniques for the sake of localization alone, this modality should be considered if the surgeon anticipates difficulty with intraoperative localization.

Conclusions

Wrong-site surgery is a rare complication that can lead to significant clinical morbidity, increased health care costs, and medical-legal consequences. This should be viewed as a preventable complication, and verification of the intended site of surgery preoperatively is critical; standardized checklists can help facilitate this process. Recognition of the unique challenges in spinal localization should be acknowledged, and there are many strategies that are safe and easy to implement that can help to ensure accurate intraoperative localization.

Disclosure

The authors have the following conflicts of interest to report. Dr. Gokaslan reports direct stock ownership in US Spine and Spinal Kinetics; clinical or research support for this study (includes equipment or material) from DePuy Spine, AO Spine North America, Medtronic, and Neurosurgery Research and Education Foundation; and fellowship support from AO Spine North America. Dr. Kretzer reports research grants for biomechanical studies unrelated to the topic of this manuscript from DePuy Spine, and he is a consultant for Chestnut Medical Technologies.

Author contributions to the study and manuscript preparation include the following. Acquisition of data: Hsu. Drafting the article: Hsu. Critically revising the article: Kretzer, Dorsi. Study supervision: Gokaslan.

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Manuscript submitted February 21, 2011.
Accepted July 14, 2011.

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Neurosurg Focus 31 (4):E6, 2011

Complication avoidance and management in anterior lumbar interbody fusion

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The goal of this study was to review the literature to compare strategies for avoiding and treating complications from anterior lumbar interbody fusion (ALIF), and thus provide a comprehensive aid for spine surgeons. A thorough review of databases from the US National Library of Medicine and the National Institutes of Health was conducted. The complications of ALIF addressed in this paper include pseudarthrosis and subsidence, vascular injury, retrograde ejaculation, ileus, and lymphocele (chyloretroperitoneum). Strategies identified for improving fusion rates included the use of frozen rather than freeze-dried allograft, cage instrumentation, and bone morphogenetic protein. Lower cage heights appear to reduce the risk of subsidence. The most common vascular injury is venous laceration, which occurs less frequently when using nonthreaded interbody grafts such as iliac crest autograft or femoral ring allograft. Left iliac artery thrombosis is the most common arterial injury, and its occurrence can be minimized by intermittent release of retraction intraoperatively. The risk of retrograde ejaculation is significantly higher with laparoscopic approaches, and thus should be avoided in male patients. Despite precautionary measures, complications from ALIF may occur, but treatment options do exist. Bowel obstruction can be treated conservatively with neostigmine or with decompression. In cases of postoperative lymphocele, resolution can be attained by creating a peritoneal window. By recognizing ways to minimize complications, the spine surgeon can safely use ALIF procedures.
(DOI: 10.3171/2011.7.FOCUS11141)

Key Words • **anterior lumbar interbody fusion** • **anterior spine** • **complication** • **lumbar spine**

Anterior lumbar interbody fusion is a valuable technique in the field of spine surgery. The advantages of ALIF are numerous. By accessing the lumbar spine via an abdominal incision, there is greater exposure of the anterior column, less muscular retraction with less blood loss, and reduced operative time. Access to the complete disc space allows greater distraction, and thus the ability to correct deformity as well as the ability to place larger interbody devices, increasing the likelihood of arthrodesis. Anterior lumbar interbody fusion is superior to transforaminal lumbar interbody fusion in its capacity to restore foraminal height, local disc angle, and lordosis, potentially improving sagittal balance and leading to better long-term outcomes.[12] Manipulation and subsequent scarring of nervous structures are avoided, and in certain situations the canal and neural foramina can be indirectly decompressed. In addition, other stabilizing elements such as the dorsal bone, soft tissue, and associated tension bands are kept intact.

Abbreviations used in this paper: ALIF = anterior lumbar interbody fusion; BMP = bone morphogenetic protein.

Despite these advantages, there are unique disadvantages to the procedure. A study of 447 patients by McDonnell et al.[21] found that 11% of patients experienced major complications and 24% experienced minor complications after anterior surgical approaches to the spine. This set of complications is atypical in the realm of more standard neurosurgical procedures, and include injuries to abdominal viscera, the abdominal wall, great vessels, ureter, and numerous nerve plexuses.

The goal of our study was not to review the literature for the incidence of complications from ALIF, but rather to evaluate strategies for avoiding and treating those complications. By doing so, we hope to provide a framework for the safe use of ALIF.

Methods

Records from databases of the US National Library of Medicine and the National Institutes of Health (www.pubmed.gov) were queried to identify all studies pertaining to ALIF. The terms "anterior lumbar interbody fusion" and "ALIF" were used as search key words, and

all English-language articles were perused for mention of complication rates and management strategies. Reference lists of all relevant articles were examined to identify additional studies.

Results

Pseudarthrosis

Pseudarthrosis, or nonunion, is a complication of any fusion technique, whether it be an anterior or posterior method. In a systematic review by Jacobs et al.,[15] the authors found a fusion rate ranging between 47% and 90% for ALIF, with most cited fusion rates approaching 90%. Several studies have identified factors that may decrease the incidence of pseudarthrosis, including graft/cage preparation and usage, the use of biologics, and the addition of supplemental instrumentation.

Thalgott et al.[31] performed a study in which 50 patients undergoing ALIF were randomized to receive either frozen or freeze-dried femoral ring allograft. Six of 7 patients who experienced pseudarthrosis received the freeze-dried allograft, suggesting a benefit for frozen allograft products as opposed to freeze dried, although a mechanism for this difference was not proposed. Madan et al.[20] compared 27 patients who received noninstrumented ALIF (that is, graft only) with 29 patients who received instrumented ALIF (that is, graft and cage). The authors found a significant difference in fusion rates between the 2 groups of 83.3% and 100%, respectively, arguing for the use of instrumentation in ALIF procedures.

The use of biologics in spine surgery has become prevalent, particularly with the advent of BMPs. In 2004, Burkus[5] reported on a prospective, multicenter, randomized study in which 22 patients undergoing ALIF received autograft, whereas 24 patients received a recombinant human BMP-2–coated absorbable collagen sponge carrier and allograft bone dowels. The 2-year radiographic fusion rates were 68.4% and 100%, respectively. This study was repeated with nearly 3 times the number of patients and produced similar results (2-year fusion rates of 81.5% and 100%, respectively).[6] However, Pradhan et al.[24] found that the use of BMP with femoral ring allograft produced the opposite result, with pseudarthrosis occurring in 36% of patients with iliac crest bone graft/femoral ring allograft and in 56% of patients with femoral ring allograft and BMP-2. This difference was attributed to aggressive BMP-induced resorption. Thus, BMP can augment bone fusion, but only in the proper environment.

Lastly, whereas a number of studies have shown greater fusion rates in ALIF when supplemented posteriorly, the guidelines set forth in 2005 by Resnick et al.[25] do not advocate a circumferential fusion in the setting of 1- or 2-level disc disease, citing much higher rates of complications when an additional posterior approach is used.

Subsidence

Subsidence is "a decrease in the vertical height of the disc space prior to complete incorporation of the fusion mass."[7] The goal in any interbody fusion procedure is to restore disc height and neural foramina caliber; the occurrence of subsidence is therefore counterproductive. Beutler and Peppelman[2] identified increased reaming depth and larger cage sizes as risk factors for subsidence. In terms of the latter, the average cage sizes for patients who did and did not develop subsidence were 16.1 mm and 14.7 mm, respectively. In osteoporotic patients, Kim et al.[18] found that augmenting the ALIF with vertebral body injections of polymethylmethacrylate (a vertebroplasty) resulted in a significantly decreased degree of cage subsidence. It should be noted, however, that these patients underwent supplemental pedicle screw fusions posteriorly.

Vascular Complications

The abdomen contains anatomy unfamiliar to most neurosurgeons, and many vascular structures are exposed and at risk for injury during ALIF. These structures include the great vessels, segmental vessels, and numerous veins. Anatomically, the abdominal aorta bifurcation is usually found at the level of the L-4 vertebral body, while the confluence of the inferior vena cava is usually located at the level of the L-5 vertebral body.[14]

Vascular injury during ALIF was thoroughly reviewed by Inamasu and Guiot.[13] These authors found that vascular injury most often occurred when operating at the L4–5 level, given the aforementioned anatomy. Venous laceration was the most common vascular injury and usually occurred during retraction of the great vessels. Other mechanisms of injury included performing the discectomy, placing the graft, and removing the temporary pin. The veins most commonly lacerated were the left common iliac vein, inferior vena cava, and iliolumbar vein. Manual compression and/or primary suture were generally effective at treating this complication. Sasso et al.[26] found that venous injury was significantly more common when using threaded fusion devices (such as machined bone dowels and cylindrical titanium implants) compared with nonthreaded ones (such as iliac crest autograft and femoral ring allograft). This finding was attributed to the added instrumentation needed to place threaded devices.

In their review, Inamasu and Guiot[13] found that the most common arterial injury occurring during ALIF is left iliac artery thrombosis. This complication occurs due to prolonged retraction of the common iliac arteries to the right, causing diminished arterial flow and subsequent left-sided thrombosis. Treatment of this complication is considered an emergency and involves thrombectomy and/or bypass surgery. Preventative strategies proposed include intermittent release of the retraction intraoperatively, and lower-extremity pulse oximetry during and after the procedure.[3,4,19] Injury to the bilateral inferior epigastric arteries has also been reported.[30]

In a retrospective review of prospectively collected data on 212 patients who underwent ALIF, Garg et al.[11] found a significantly increased risk of vascular injury when 2 spinal levels were instrumented, and in male patients. The authors advocated preoperative evaluation and intraoperative exposure by a vascular surgeon. At our institution, exposure is provided by our colleagues in general surgery.

Postoperative Adynamic Ileus Versus Acute Colonic Pseudoobstruction

Adynamic postoperative ileus is a major determi-

nant of length of stay following abdominal operations.[23] Postoperative ileus occurs most commonly in patients undergoing major bowel operations, and is recognized as a common reason for delayed hospital discharge following these operations.[9] Postoperative ileus is also frequently observed in extraperitoneal abdominal operations, including ALIF, and portends an increased risk of hospital readmission and increased health care costs overall.[28] In addition, postoperative ileus stands as a barrier to effective pain management in many of these patients. Three general pathogenic mechanisms of postoperative ileus are typically cited—neurogenic, inflammatory, and pharmacological. Human and animal experimental evidence suggests that reactive hyperactivity of the sympathetic nervous system overcomes normal parasympathetic-driven gastrointestinal smooth-muscle activity, diminishing normal gastrointestinal motility.[23] Detailed explanation of the mechanisms by which postoperative ileus occurs is beyond the scope of this article; however, the effects of postoperative ileus following ALIF can potentially be diminished by optimizing postoperative medication regimens and nutrition, as well as using nonnarcotic pain control strategies.

A diagnostic quandary occasionally arises after ALIF in differentiating postoperative ileus from Ogilvie syndrome. Acute colonic pseudoobstruction, as Ogilvie syndrome is now known, was described by William Ogilvie in 2 patients with intraabdominal malignancy. Whereas the vagus nerve carries parasympathetic innervation to the esophagus, stomach, small intestines, and proximal colon, the sacral plexus provides parasympathetic innervation to the distal colon. Ogilvie hypothesized that these masses impinged upon his patients' sacral plexuses, resulting in disruption of normal parasympathetic innervation.[22] Though the exact mechanism of acute colonic pseudoobstruction remains uncertain, the preponderance of cases involving retroperitoneal pathologies or spinal anesthesia suggests that pathology at the level of the sacral plexus is involved. The high efficacy of parasympathomimetic agents in the treatment of acute colonic pseudoobstruction suggests that dysregulation of colonic autonomic function is involved. Although uncommon, acute colonic pseudoobstruction can result in cecal perforation in as many as 20% of cases,[16] which has an associated mortality rate of 25%–60%.[1]

Acute colonic pseudoobstruction has been diagnosed as a postoperative condition in 50%–60% of cases,[33] and as a common medical condition (including metabolic and oncological). Mechanical disruption of parasympathetic innervation to the colon is typically believed to cause acute colonic pseudoobstruction, and both the intraperitoneal and retroperitoneal approaches in ALIF pose this risk. This is believed to occur both by direct manipulation of these nerves and by retroperitoneal hematoma. In addition, the risk of ischemic insult to the sacral plexus has also been hypothesized to contribute to acute colonic pseudoobstruction, given the relatively high incidence rate noted in vasculopathic patients. In 1 series, 22% of postoperative acute colonic pseudoobstruction cases were observed following spinal cases and 25% after coronary artery bypass grafting.[29] Acute colonic pseudoobstruction has been reported to occur following posterior spinal operations as well as in ALIF.

Colonic distension can be caused by a number of mechanisms including metabolic, mechanical, septic, and pharmacological. Postoperative ileus, toxic megacolon, and mechanical obstruction must be considered as well when diagnosing acute colonic pseudoobstruction. Symptoms typical of a proximal large bowel obstruction, including abdominal pain, distension, nausea, vomiting, constipation, or diarrhea, might suggest the need for further investigation. Colonic dilation is typically observed from the cecum to the splenic flexure on plain abdominal radiographs, and CT or contrasted enema should rule out mechanical obstruction. Laboratory evaluation often reveals leukocytosis or metabolic derangement. Aggressive correction of metabolic abnormalities, nasogastric suction, bowel rest, and regularly scheduled enemas should be included in the strategy for initial conservative management.

Intravenous neostigmine (using a standard dose of 2.0 mg) is typically the second-line intervention and, among prospective series, has shown a long-term efficacy rate of 64%–100%.[8] Administration of neostigmine should be performed with the patient supine, with continuous cardiopulmonary monitoring and with atropine readily available. Side effects of neostigmine can be diminished by reducing dosage or by coadministration of glycopyrrolate.

The third-line intervention is colonoscopic decompression. Surgical interventions such as percutaneous colostomy and surgical cecostomy are appropriate in symptomatic patients with extreme colonic dilation (often defined as 12–13 cm, but the utility of radiographic criteria for this condition is unsubstantiated), in whom other more conservative measures have failed.

Retrograde Ejaculation

Retrograde ejaculation can complicate any abdominal surgery in male patients due to injury of the superior hypogastric plexus, which lies beneath the peritoneum, courses anterior to the aorta, and crosses anterior to the left common iliac vein. The one consistent finding in the literature regarding retrograde ejaculation is its increased incidence with the use of laparoscopic approaches. Kaiser et al.[17] found the rate of retrograde ejaculation to be 45% with laparoscopic approaches compared with 6% in cases using a mini-open approach. Similarly, Escobar et al.[10] found rates of 25% and 2%, respectively. The association between laparoscopy and retrograde ejaculation is due to the transperitoneal nature of laparoscopy and the proximity of the superior hypogastric plexus to the peritoneum. The utilization of laparoscopic ALIF appears to be diminishing, given the feasibility of open and mini-open surgical approaches.

Lymphocele

Postoperative lymphocele, or chyloretroperitoneum, is an uncommon complication following anterior spine surgery. Lymph vessels and nodes are numerous around the spinal column, and persistent leakage can result in lymphedema, mechanical compression, nutritional deficiencies,

immunosuppression, and death.[32] There is no data available to suggest the best way to avoid lymphatic injury. Typical management options include observation and drainage. Schizas et al.[27] reported good results in 1 case treated via laparoscopic marsupialization. At our institution, we treated chyloretroperitoneum via a peritoneal window, which was performed (by a general surgeon) by creating an opening in the posterior peritoneal wall to allow the lymph to drain into the peritoneal space.[32] We have since used the peritoneal window to treat 2 additional patients with chyloretroperitoneum, without recurrence.

Discussion

Including ALIF as part of one's surgical armamentarium provides a useful tool for treating a number of spinal pathologies. Anterior lumbar interbody fusion is a superior method of restoring foraminal height and focal lordosis, making it an important tool for correction of lumbar lordosis and deformity. However, it is important for spine surgeons to be aware of the complications that may result from the ALIF approach, as well as knowledge of how to avoid and treat the complications that inevitably will occur. Rather than evaluate articles that report the incidence and types of complications associated with ALIF, our goal was to compare strategies for avoiding and treating such adverse outcomes. In this respect, the literature available was much more limited. Based on these studies as well as our own practices, we present the following recommendations.

The use of interbody cages compared with allograft placement results in higher fusion rates. The combination of recombinant human BMP-2 with allograft appears superior to autograft and minimizes the likelihood of pseudarthrosis. Frozen femoral ring allograft appears to be a viable alternative interbody implant that will avoid the added instrumentation and manipulation required with cage placement, which frequently is associated with venous injury. If interbody cages are used, lower cage heights will decrease the risk of subsidence.

Whereas venous injury is the most common complication of ALIF, arterial injury is the most serious. Careful preoperative evaluation to assess for symptoms of vascular claudication in conjunction with a physical examination to palpate lower-extremity pulses should be performed in any patient for whom an ALIF is considered. Worrisome findings during this examination should prompt a referral to the vascular surgery department. Intraoperatively, arterial injury can be avoided by using lower-extremity pulse oximetry and intermittently releasing retraction of the great vessels. Venous injury (laceration) can be avoided by careful manipulation of the retractors. Manual compression and/or primary suture should be used when laceration occurs.

Postoperative ileus following ALIF can be minimized with bowel rest until signs of gastrointestinal motility are manifested (such as bowel sounds and passing gas) and by avoiding constipating medications (such as narcotics). Acute colonic pseudoobstruction (Ogilvie syndrome) can usually be treated conservatively, although neostigmine or decompression is occasionally warranted.

Finally, the laparoscopic approach should be avoided in male patients, given the evidence for an increased rate of retrograde ejaculation. In addition, the use of electrocauterization should be minimized in the vicinity of the superior hypogastric plexus (dorsal to the peritoneum).

Conclusions

While the incidence of complications from ALIF can be relatively high compared with more common spinal surgical procedures, knowledge of these complications and the use of strategies to avoid them will allow the spine surgeon to use this technique safely.

Disclosure

Dr. Park serves as a consultant to DePuy Spine and Globus.

Author contributions to the study and manuscript preparation include the following. Conception and design: La Marca. Acquisition of data: Than, Wang, Rahman, Wilson. Analysis and interpretation of data: Wang, Wilson. Drafting the article: Than, Wilson. Critically revising the article: Park, Valdivia. Reviewed submitted version of manuscript: Park, Than, Valdivia. Approved the final version of the manuscript on behalf of all authors: Park. Study supervision: Park, Rahman, Valdivia, La Marca.

Acknowledgment

The authors would like to thank Holly Wagner for providing editorial assistance in the preparation of this manuscript.

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Manuscript submitted June 14, 2011.
Accepted July 19, 2011.

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Neurosurg Focus 31 (4):E7, 2011

Avoiding pitfalls in anterior screw fixation for Type II odontoid fractures

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Anterior screw fixation of Type II odontoid fractures provides immediate stabilization of the cervical spine while preserving C1–2 motion. This technique has a high fusion rate, but can be technically challenging. The authors identify key points that should be taken into account to maximize the chance for a favorable outcome. Keys to success include proper patient and fracture selection, identification of suitable screw entry point and correct screw trajectory, achieving bicortical purchase, and placing 2 screws when feasible and applicable. The authors review the operative technique and present guidance on appropriate patient selection and common pitfalls in anterior screw fixation, with strategies for avoiding complications. *(DOI: 10.3171/2011.7.FOCUS11135)*

Key Words • **anterior odontoid screw fixation** • **odontoid fracture** • **complication**

Odontoid fractures account for 5%–15% of all cervical spine injuries and are seen more frequently in elderly patients. Anderson and D'Alonzo[5] Type II fractures—at the base of the dens—are the most common odontoid injury and produce atlantoaxial instability.[13] Such fractures compromise the integrity of the atlantoaxial complex, allowing abnormal movement that may result in compression of the cervical spinal cord and possible spinal cord injury. Nonoperative management with immobilization in a rigid brace or halo vest is associated with high morbidity and significant failure rates,[6,12,35,37,48,55,58] particularly in high-risk populations. Several surgical stabilization options are available; however, there is no consensus on the best treatment management.[16,60] Posterior atlantoaxial fusion techniques, such as placement of C1–2 transarticular screws, have a high fusion rate; however, these options can be technically demanding. Furthermore, fusion of the atlantoaxial complex, which provides the largest amount of rotation in the cervical spine,[45] restricts this movement more than 50%.[25] In contrast, direct anterior screw fixation provides immediate stability, relatively high rates of fracture healing, and preserved C1–2 motion.[22,40] We review this operative technique and present guidance on appropriate patient selection and common pitfalls of anterior screw fixation, with strategies for avoiding complications.

Abbreviations used in this paper: TAL = transverse atlantal ligament; VB = vertebral body.

Surgical Technique

Anterior screw fixation of odontoid fractures is typically completed via an anterior retropharyngeal approach. This technique has been previously described in detail by Apfelbaum et al.[7] Presurgical positioning and planning is critical for optimal screw placement. The patient is positioned supine on the operating table and placed in cervical traction to maximize fracture reduction, which is confirmed by fluoroscopy. An incision is made at the C-5 level along a natural skin crease. Dissection is completed carefully through anatomical tissue planes to the anterior aspect of the C-5 and C-6 VBs. Blunt dissection is continued in the retropharyngeal space to fashion a tunnel to the C-2 VB. A self-retaining retractor system is then positioned to facilitate rostral retraction. Under fluoroscopic guidance, a K-wire is inserted into the inferior aspect of the C-2 VB, with entry planning based on whether 1 (midline entry site) or 2 (paramedian entry sites) odontoid screws will be used. A hollow, 8-mm, hand-rotated drill is placed over the K-wire to burrow a path through the face of C-3 and the C2–3 disc space to the inferior aspect of the anterior lip of C-2. The drill guide system is then placed over the K-wire, and the outer guide tube is firmly set into C-3. This allows for gentle manipulation to align the C-2 and C-3 vertebrae relative to the odontoid and C-1 for an accurate screw trajectory. The K-wire is removed and replaced by the drill bit. The site is drilled and tapped, and a lag screw of appropriate length is placed.

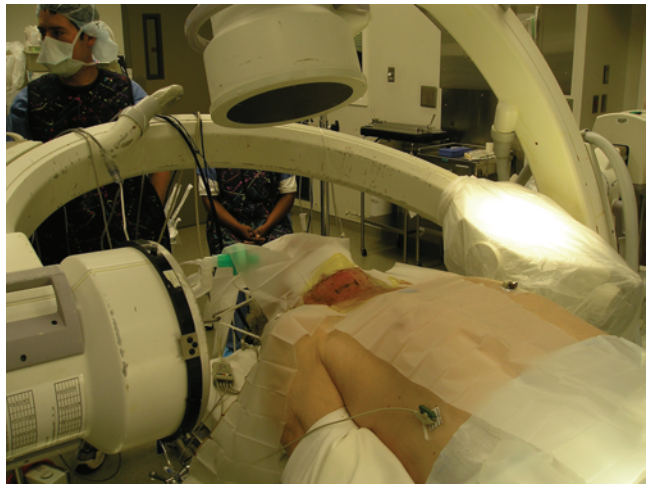


Fig. 1. Intraoperative photograph of 2 C-arms positioned for biplanar fluoroscopy to guide odontoid screw placement for anterior fixation.

All critical maneuvers should by monitored closely by using biplanar fluoroscopy (Fig. 1). After screw placement, dynamic flexion and extension fluoroscopic images should be obtained to confirm atlantoaxial stability.

Alternatives to and variations on the above approach for anterior fixation of odontoid fractures have been described. Image guidance in combination with neuronavigation provides an alternative to fluoroscopy for real-time intraoperative data acquisition and accurate placement of instrumentation.[29] Technical reports have been published on minimally invasive surgery, including endoscopic[26] and percutaneous techniques.[11,36] The theoretical advantages of a minimally invasive procedure include the following: reduced operating time; less surgical exposure, manipulation of soft tissues, and blood loss; and better preservation of anterior anulus, disc, and bone.[11,59] These techniques, however, are technically challenging. Because the percutaneous procedure is performed without direct visualization, familiarity with cervical anatomy is vital for avoiding injury to soft tissues during drilling and tapping. Endoscopically assisted surgery provides operative field visualization with a small skin incision, but evidence on the efficacy of using an endoscopic approach is lacking. Moreover, neither percutaneous nor endoscopic techniques allow for drill guides that can be affixed to the spine, thereby limiting manipulation of the C-2 VB for alignment of fracture fragments.

Patient Selection

Anterior screw fixation of odontoid fractures provides a much higher rate of fusion (82%) than nonoperative management with a rigid cervical collar (51%) or halo vest (65%).[30] Patients in whom anterior fixation fails often have similar injury types, baseline characteristics, and courses of disease progression; thus, careful patient selection can ensure better outcomes. The following factors have been associated with poor outcomes after anterior screw placement.

Morphological Features of the Fracture

Anterior odontoid screw placement is ideal for a Type II fracture that courses obliquely from the anterosuperior to the posteroinferior portion of the dens, because the screw can be inserted perpendicular to the fracture. This fracture pattern is classified as a Grauer Type IIB injury.[23] An oblique fracture line from posterosuperior to anteroinferior that would parallel screw trajectory is a contraindication to anterior fixation, because interfragmentary compression by the odontoid screw cannot occur.[1] Some authors have also cautioned against anterior screw fixation for oblique fracture lines in the coronal plane, because tightening of the lag screw could cause lateral drifting of the apical fragment, resulting in atlantoaxial incongruency.[31]

Bone quality at the fracture site should also be taken into account, because Type II odontoid fractures may be physiologically prone to poor healing. Cancellous bone heals faster than cortical bone, and fractured trabeculae are the sites for fracture repair.[4] The base of the odontoid process is hypodense[28] and contains 55% fewer trabeculae than the axis and the odontoid process itself.[3] Patients with severe osteoporosis,[40] comminution of the fracture,[6] additional fractures of the body of C-2, or Type II odontoid fractures with severe angulation and displacement that cannot be completely reduced preoperatively may have insufficient bone quality to maintain screw fixation, and are poor candidates for anterior screw placement (Fig. 2).[15] Proximal screw pullout and repeated fracture displacement

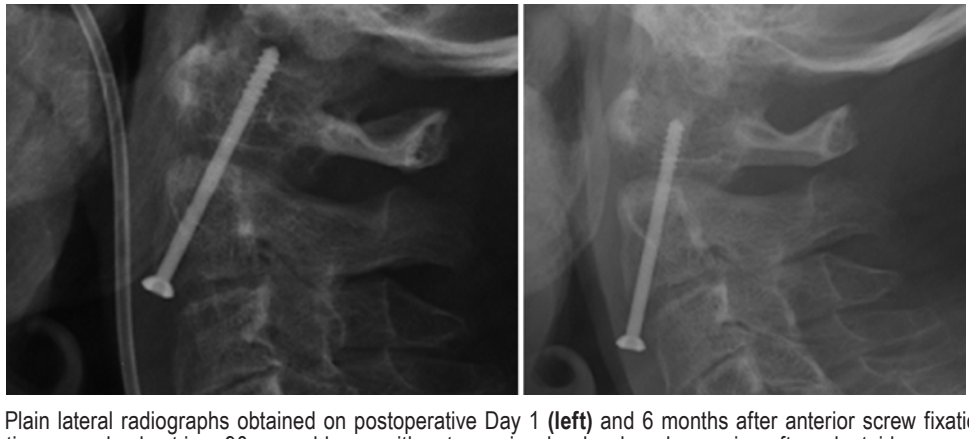


Fig. 2. Plain lateral radiographs obtained on postoperative Day 1 **(left)** and 6 months after anterior screw fixation **(right)**, demonstrating screw backout in a 90-year-old man with osteopenia who developed nonunion after odontoid screw placement. The screw backout probably resulted from poor bone quality.

in osteoporotic individuals have been reported.[1,56] Aebi et al.[1] described anterior screw migration into the spinal canal in a patient with osteopenic bone that collapsed after odontoid screw placement. Apfelbaum et al.[7] reported that screw pullout from the body of C-2 prior to development of fusion was the most common hardware-related failure, occurring in 5 of 117 patients. Each of these patients had a fracture extending into the body of C-2, and the authors recommended avoiding anterior fixation in patients with evidence of comminuted C-2 VB fractures.

Anatomical Considerations

Patient anatomy may preclude successful anterior screw fixation. It is critical that the patient's body habitus allows for a direct screw trajectory that follows the curvature of the spine. Those with a barrel chest, short neck, subaxial cervical spondylosis, or severe thoracic kyphosis may have anatomy that would impede appropriate drill and screw placement (Fig. 3). Perioperative positioning before surgery requires placing the patient in traction to extend the cervical spine and using fluoroscopy both to visualize fracture reduction and to verify an unimpeded trajectory for screw insertion. Such cervical manipulation may cause injury in some patients. Patients with severe spinal canal stenosis, such as those with posterior osteophytes of the cervical vertebrae, may be poor candidates for anterior screw fixation, lest placing the patient in the amount of cervical lordosis necessary for screw placement cause injury to the cervical spinal cord.[31]

Some patients may have concomitant injuries at the atlantoaxial junction for which motion preservation would not be favorable. For example, injury to the C1–2 joints and intraarticular fractures may cause painful posttraumatic arthrosis, and the presence of an unstable Jefferson fracture would result in persistent C1–2 subluxation.[31] In these cases, posterior C1–2 fusion is preferable to anterior screw fixation.

Chronic Nonunion

Immediate fixation of odontoid fractures provides the best chance of fracture healing. Nevertheless, nonunion of odontoid fractures is a relatively common complication in patients treated nonsurgically and those in whom the diagnosis was delayed. Many authors have reported nonunion rates of 40% or greater in patients without operative stabilization.[30,35,38] Persistent atlantoaxial instability is the primary concern when odontoid fractures fail to heal and pseudarthrosis develops. Patients may present with C-2 nerve root pain, neck stiffness, radiculopathy, or myelopathic symptoms, such as weak hands and difficulty walking,[13,46] although some experience no neurological problems at all.

Outcomes vary in patients who undergo anterior fixation after remote odontoid fractures. Aebi et al.[1] reported screw fracture in a 20-year-old patient who presented with a 22-month-old nonunion of the dens. Agrillo et al.[2] reported on a series of 9 patients who underwent anterior screw fixation for nonunited odontoid fracture 6–12 months after the traumatic event. Bone fusion was observed in 7 patients (77%) 4–16 months after fixation. One patient developed a stable fibrous union 14 months after surgery. Anterior fixation failed in 1 patient for whom 11 months had elapsed from the traumatic injury until surgical intervention. Fracture diastasis was observed in this patient 6 months after anterior fixation, and subsequent posterior stabilization was performed. Apfelbaum et al.[7] evaluated 16 patients who underwent anterior fixation 18 or more months after injury, and reported a technical complication rate of 25%, which was considerably higher than that of patients with fractures less than 6 months old (9%). Three patients in this series experienced screw fracture (Fig. 4), and 1 patient had screw backout. Moreover, the anatomical fusion rate in patients with remote fractures was significantly lower (25%) than that in patients with recent fractures (88%). From these data, the authors concluded that the rate of successful bone fusion inversely correlates with the age of the fracture.

Incompetence of the TAL

Incompetence of the TAL results in atlantoaxial instability regardless of whether the odontoid process remains intact. The TAL provides the most anterior stability of all the components of the atlantoaxial complex. If the TAL is ruptured, the auxiliary ligaments usually are inadequate to prevent anterior subluxation of C-1 on C-2.[20] In cases of Type II odontoid fracture, instability will persist even after successful bone fusion is achieved.[24] Therefore, disruption of the TAL is a contraindication for anterior

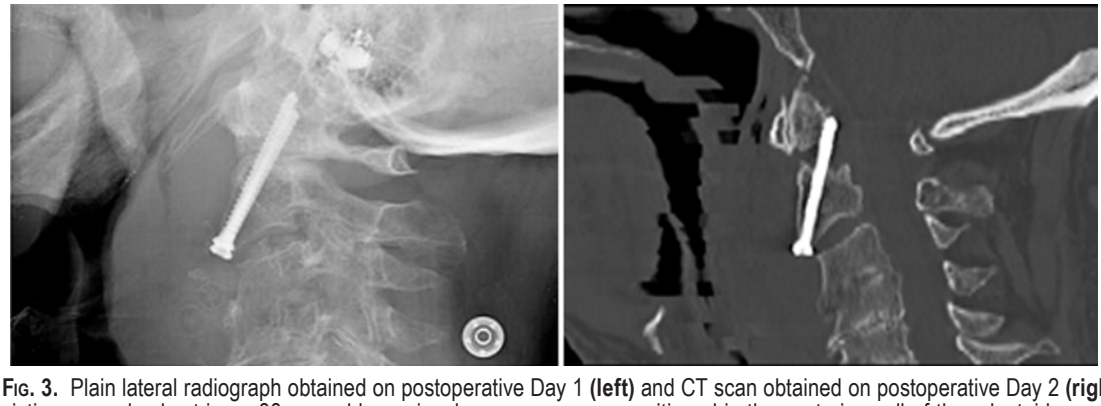


Fig. 3. Plain lateral radiograph obtained on postoperative Day 1 **(left)** and CT scan obtained on postoperative Day 2 **(right)**, depicting screw backout in an 88-year-old man in whom screws were positioned in the posterior wall of the odontoid process because his body habitus did not allow for screw placement into the odontoid tip.

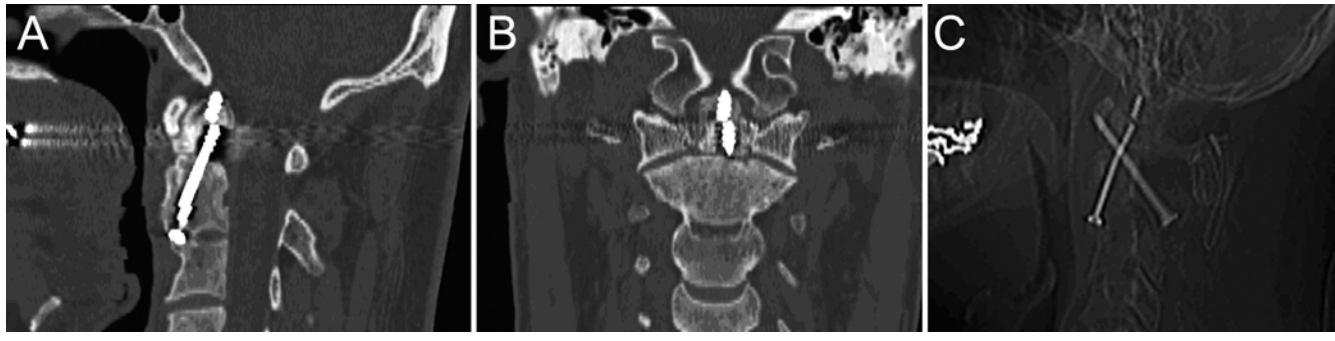


Fig. 4. Postoperative CT scans **(A and B)** demonstrating screw fracture in a 42-year-old man who underwent anterior screw fixation for chronic nonunion of a remote odontoid fracture several months after halo immobilization had failed. He subsequently underwent successful posterior C1–2 fusion with placement of transarticular screws **(C)**.

screw fixation for odontoid fractures. The incidence of concomitant TAL disruption and odontoid fracture is low. In a study of 30 patients with odontoid fractures, Greene et al.[24] reported a 10% incidence of TAL injury and advocated the use of MR imaging to assess TAL integrity as a part of the initial evaluation of all odontoid fractures. In a study of 77 patients with odontoid fractures, however, Sayama et al.[51] reported no cases of atlantoaxial instability, and these authors recommended MR imaging screening only if patients present with neurological deficits or widening of the atlantodental interval greater than 3 mm on radiographs or CT scans.

Pathological Fracture

Reports of anterior fixation of pathological dens fractures describe high morbidity rates and poor outcomes.[33,34,41,54] The consensus considers a pathological fracture to be a contraindication to odontoid screw placement.[15,21] Metastatic tumors involving the upper cervical spine are rare, involving < 1% of patients with spinal metastases.[27] When metastatic disease occurs at the atlantoaxial spine, the most common location is at the junction between the dens and the axial body.[42] Patients typically report severe neck pain secondary to spinal instability.[9,57] Neurological deficits, however, are not common,[9,42,49] which may be due to the increased size of the upper cervical canal compared with other spinal levels. After tumor removal, rigid fixation is difficult to achieve technically by using anterior fixation alone, and subsequent posterior stabilization is often required.[54] Furthermore, the goals of care often differ in cancer patients and in those who have a traumatic odontoid fracture. Rather than aiming toward preservation of long-term atlantoaxial mobility, in patients with cancer the surgery is palliative, with goals of decreasing mechanical neck pain and preventing neurological deterioration.[21] Cancer patients may have limited life expectancy, and many require adjuvant chemotherapy or radiotherapy that compromises the chance of a successful osseous fusion.

Avoiding Complications During Anterior Screw Fixation

Anterior screw fixation of odontoid fractures is a technically challenging operation, but when performed correctly, atlantoaxial stability is restored immediately, the likelihood of fracture healing is high, and patients maintain anatomical motion along the C1–2 axis. Common pitfalls include poor patient positioning, improper screw trajectory, and inadequate screw purchase. Intraoperative complications may result in hardware failure, inability to reduce the fracture, or persistent atlantoaxial instability. When anterior screw fixation fails, posterior cervical fusion is usually performed as a salvage operation. We discuss strategies to avoid these pitfalls and maximize the chance for a successful result.

Perioperative Positioning

Proper perioperative positioning is the foundation of successful odontoid screw placement. Care must be taken to extend the patient's head as much as possible without causing repeat dislocation of the fracture. Poor head positioning and inadequate fracture reduction at the time of surgery create a propensity for posterior malalignment of the dens.[1] Adequate extension of C-2 enables the screw trajectory to be directed accurately along the axis of the odontoid process. Improper positioning or poor patient body habitus may render screw insertion difficult or impossible. The presence of a direct trajectory must be verified under fluoroscopy before surgery is started. If satisfactory positioning cannot be achieved, the attempt at anterior screw fixation should be abandoned and posterior fusion of C1–2 should be performed.

The surgical technique we describe calls for the use of a specific drill guide that can be affixed to the spine. These drill guides have spikes that attach to the C-3 VB, thereby enabling the surgeon to manipulate the C-2 VB and align the fracture fragments to further optimize screw trajectory. Certain minimally invasive endoscopic and percutaneous techniques for odontoid screw placement have been described that aim to minimize surgical exposure. Although the theoretical advantages are favorable, including reduced operating time and less manipulation of soft tissues, such techniques do not enable the use of drill guides that can be affixed to the spine. Because they do not allow for the same extent of manipulation and fracture reduction that the technique we describe, which is performed using a C-3 VB–affixing drill guide, affords, we do not recommend minimally invasive approaches to anterior screw fixation.

Selection of Screw Entry Point

Before establishing a screw trajectory, it is critical to identify the precise entry point. Entry should be placed under the anterior lip of C-2 and not on the anterior body of the vertebra. Incorrectly positioning screw entry at the anterior body of C-2 predisposes to screw breakout, screw pullout, loss of fracture reduction, and subsequent nonunion. Furthermore, this trajectory increases the likelihood for posterior angulation, fragment malalignment, persistent anterior fracture gap, and prolonged healing time.[1] Placing the entry point too close to the anterior surface of C-2 also carries the risk of causing breakout of the K-wire, drill bit, or odontoid screw through the anterior VB. This would result in inadequate screw purchase, resulting in immediate abandonment of anterior fixation and conversion to a posterior fusion, or risk potential nonunion (Fig. 5).

Proper K-Wire Use

A K-wire is used in cannulated screw systems to direct screw trajectory accurately, enabling continuous fixation and avoiding migration of unstable bone fragments during screw insertion.[17] Hollow tools and hollow screws are inserted into the bone over the K-wires and are advanced to the tip of the dens, but once the K-wire engages bone, its position cannot be altered without it being removed completely by reversing the drill direction and then reinserting it at a new entry point to define a new track. Manipulation of the drill guide with the K-wire engaged may create excessive torque, causing the K-wire to break. Dickman et al.[17] described the technique of attaching the end-threaded K-wire to a reversible pneumatic drill to advance the tip of the K-wire into the dens. Others recommend using a noncannulated bit to drill through the cortex at the tip of the odontoid so that breakage of the K-wire is avoided and the K-wire cannot be captured by the drill and driven through the distal cortex and beyond.[15]

Bicortical Screw Fixation

Both unicortical and bicortical fixation have been described. Bicortical fixation maximizes interfragmentary compression, but is associated with a risk for guidewire or screw migration beyond the apex and associated neural or vascular injury. Because of this, some authors recommend unicortical fixation, in which either a fully threaded variable-pitch screw[39] or a cannulated cancellous lag screw[19] is used. Biomechanical studies have demonstrated a favorable comparison between unicortical and bicortical fixation.[39] Clinical studies, however, describe complications associated with unicortical fixation, which suggests that bicortical fixation may provide a better result (Fig. 6). Apfelbaum et al.[7] observed screw backout in 4 patients whose screws were only partially engaged in the apical odontoid cortex. One patient became quadriplegic and then died of respiratory causes after a screw backed out and fractured distally, causing displacement of the fragment. The authors concluded that ensuring adequate purchase in the distal fragments by having the screw threads cross the apical cortex is critical to optimize fracture healing.

If a bicortical fixation technique is used, care must be taken to drill through the distal cortex so the lag screw will engage the cortex and compress the distal fragment and proximal C-2 body together.[15] Moreover, if a screw is placed that is too short to engage the distal cortex of the fracture segment, the operation can probably be salvaged with replacement by a longer screw that has bicortical purchase.

Single-Screw and Dual-Screw Fixation

Osteosynthesis via an anterior odontoid screw pro-

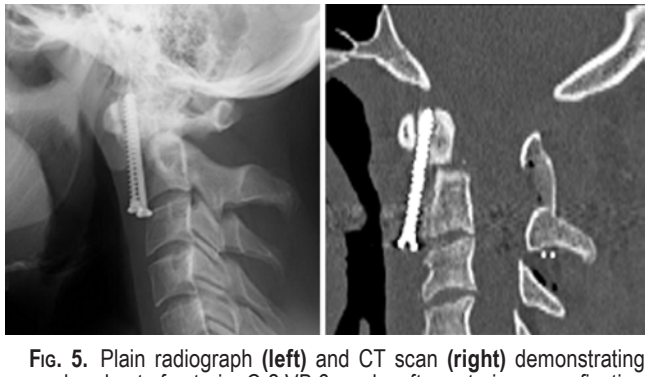


Fig. 5. Plain radiograph **(left)** and CT scan **(right)** demonstrating screw breakout of anterior C-2 VB 6 weeks after anterior screw fixation in a 22-year-old man. Screw breakout occurred because the placement of the entry point was too anterior and the screw had an insufficient posterior trajectory.



Fig. 6. Plain lateral radiographs **(left)** and CT scans **(right)** obtained 1 year **(upper row)** and 2 years **(lower row)** after anterior fixation of a traumatic odontoid fracture in a 28-year-old man who was involved in a motor vehicle accident. The images demonstrate chronic nonunion associated with unicortical purchase of a single odontoid screw.

vides immediate stability to approximately one-half the strength of the intact dens.[18,50] Either 1 or 2 screws have been used for fixation. Theoretically, 2 screws confer the advantage of preventing rotation of the odontoid relative to the body of C-2,[7] and this may be the preferred technique in patients with poor bone quality, because of increased rotational stability.[10] Dailey et al.[14] found that placement of 2 screws resulted in a higher fusion rate in patients aged 70 years and older (Fig. 7); however, no difference in load-bearing strength, flexion-extension and rotational stiffness, or union rate has been demonstrated consistently in biomechanical or clinical studies.[7,32] Moreover, placement of 2 screws can be technically challenging. Two 3.5-mm screws require at least 9 mm of space for appropriate placement,[43] and many patients do not have an odontoid large enough in diameter to accommodate 2 screws.[52] Given the small area of the odontoid tip, 2 screws reduce the surface area available for bone fusion to occur. This may be problematic for fracture healing, considering the decreased amount of cancellous bone present at the base of the odontoid.[3]

Other Common Complications

The rate of site-specific complications and technical problems is comparable for anterior screw fixation and posterior arthrodesis.[44,47] Major complications of anterior odontoid screw fixation include neural injury, esophageal or pharyngeal perforation, hemorrhage, and airway obstruction.[7] There is a substantial incidence of airway complications in patients undergoing anterior screw fixation. Postoperative airway complications include tracheostomy, prolonged or repeated intubation, respiratory distress, airway edema, prolonged ventilator use, aspiration, pneumonia, and swallowing or vocal cord dysfunction. Smith et al.[55] found that patients undergoing odontoid screw fixation were more likely to receive tracheotomies, contract pneumonia, and develop swallowing or vocal cord problems than those undergoing posterior procedures. Respiratory compromise due to retropharyngeal swelling adjacent to the surgical site has also been described.[30] Dailey et al.[14] found a relatively high incidence of postoperative dysphagia after anterior fixation in elderly patients with a mean age of 81 years. Thirty-five percent of the patients included required diet modification or nasogastric tube placement after surgery. Indeed, elderly patients are already predisposed to dysphagia, considering the fact that aberrant swallowing is a natural part of aging.[53] Dysphagia after anterior cervical surgery is common in the initial postoperative period and decreases with time, but a minority of patients may continue to experience symptoms at 6 months after the procedure or longer.[8] The risk of aspiration pneumonia, reported to be as high as 19% in one study on elderly patients,[14] increases in these patients with swallowing dysfunction. A postoperative swallowing study can help identify patients at risk for swallowing difficulty and may potentially decrease the risk for aspiration and subsequent pneumonia.

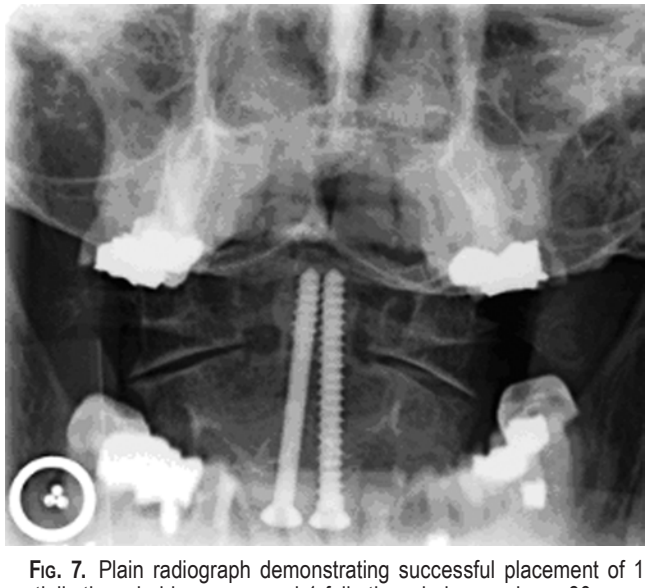


Fig. 7. Plain radiograph demonstrating successful placement of 1 partially threaded lag screw and 1 fully threaded screw in an 80-year-old woman treated for an acute odontoid fracture from a ground-level fall.

Conclusions

Anterior odontoid screw fixation is an excellent motion-preserving option for fixation of Type II odontoid fractures. Successful long-term management of these fractures relies on a multitude of factors. Based on review of the literature and the experience of the senior authors, we have identified crucial points to keep in mind when considering surgical fixation. The decision to place an odontoid screw should take into account the patient's individual anatomy, the fracture's morphological features, bone quality, and concomitant injuries. Keys to success include proper patient/fracture selection, identification of suitable screw entry point and direct screw trajectory, achieving bicortical purchase, and placing 2 screws when feasible and applicable, such as in the elderly population. Attentive postoperative care is critical for addressing the more common complications, such as dysphagia. Close postdischarge follow-up can help identify persistent atlantoaxial instability, nonunion, and hardware-related complications that can arise, such as screw breakout, backout, or migration. Critical assessment of patient characteristics, sound surgical technique, and close clinical follow-up can dramatically increase success when performing anterior fixation for an odontoid fracture.

Disclosure

Dr. Schmidt is a consultant for Aesculap. The other 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: Schmidt, Bisson. Acquisition of data: Mazur, Mumert. Analysis and interpretation of data: Mazur, Mumert. Drafting the article: Mazur, Mumert. Critically revising the article: Schmidt, Bisson. Reviewed submitted version of manuscript: Schmidt, Bisson. Approved the final version of the manuscript on behalf of all authors: Schmidt. Study supervision: Schmidt, Bisson.

Acknowledgment

The authors thank Kristin Kraus, M.Sc., for editorial assistance in the preparation of this paper.

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Manuscript submitted June 14, 2011.
Accepted July 19, 2011.
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Neurosurg Focus 31 (4):E8, 2011

Clinically relevant complications related to pedicle screw placement in thoracolumbar surgery and their management: a literature review of 35,630 pedicle screws

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Object. The technique of pedicle screw insertion is a mainstay of spinal instrumentation. Some of its potential complications are clinically relevant and may require reoperation or further postoperative care.

Methods. A literature search was performed using MEDLINE (between 1999 and June 2011) for studies on pedicle screw placement in thoracolumbar surgery. The authors included randomized controlled trials, case-control studies, and case series (≥ 20 patients) from the English-, German-, and French-language literature. The authors assessed study type, the number of patients, the anatomical area, the number of pedicle screws, duration of follow-up, type of pedicle screw placement, incidence of complications, and type of complication. The management of specific complications is discussed.

Results. Thirty-nine articles with 46 patient groups were reviewed with a total of 35,630 pedicle screws. One study was a randomized controlled trial, 8 were case-control studies, and the remaining articles were case series. Dural lesions and irritation of nerve roots were reported in a mean of 0.18% and 0.19% per pedicle screws, respectively. Thirty-two patients in 10 studies (of 5654 patients from all 39 studies) required further revision surgeries for misplaced pedicle screws causing neurological problems. None of the analyzed studies reported vascular complications, and only 2 studies reported visceral complications of clinical significance.

Conclusions. Pedicle screw placement in the thoracolumbar region is a safe procedure with an overall high accuracy and a very low rate of clinically relevant complications. *(DOI: 10.3171/2011.7.FOCUS11168)*

Key Words • **pedicle screw** • **misplaced screw** • **neurological complication** • **thoracolumbar surgery** • **management**

Pedicle screw placement is a well-known and increasingly performed technique used to achieve fixation and fusion in thoracolumbar surgery. Since its first introduction by Harrington and Tullos in 1969[18] and further development by Roy-Camille et al.,[53] Louis,[39] and Steffee et al.[56] in the late 1980s, it has become the mainstay of spinal instrumentation. This technique is used for degenerative, neoplastic, infectious, and malformative pathologies associated with axial instability. Despite technical advances over the last few decades, pedicle screw insertion is still associated with a risk of complications. Among them, the most commonly reported complication is screw malpositioning, with an overall incidence of 0%–42% in the literature.[19,42] Fortunately, more serious screw-related complications, such as neurological, visceral, or vascular, are very rare.[36,44,61] However, it is unclear whether the low reported numbers are due to a low incidence of serious complications or whether they are subject to underreporting due to authors' medicolegal considerations. Although pedicle screw accuracy remains a challenge for the spine surgeon, a misplaced screw does not necessarily have clinical consequences. Thus far, we can distinguish clinically relevant from asymptomatic screw-related complications. The first ones are defined as screw complications leading to a new neurological deficit, to new radicular pain, to vascular or visceral injury, or ones that require revision surgery. Therefore, the primary research objective for this literature review was to investigate clinically relevant screw-related complications after surgical intervention in the thoracolumbar spine.

Abbreviation used in this paper: PMMA = polymethylmethacrylate.

Methods

We conducted a literature review of the literature containing pedicle screw placement in thoracolumbar surgery. The abstracts and titles of all articles in MEDLINE (between 1999 and June 2011) were searched for

pedicle screw with each of the following keywords: complications, neurological, vascular, visceral, and outcome. We only included randomized controlled trials, case-control studies, and case series (≥ 20 patients) in the English-, German-, and French-language literature. We only took into consideration series with adult study populations and with reported neurological or nonneurological complications in which the percentage of complications per pedicle screw or at least per patient could be extracted. Additionally, a review of all cross-references from these identified articles was performed. From the qualifying articles, the following parameters were collected: study type, number of patients, anatomical area (thoracic, lumbar, or both), number of pedicle screws, duration of follow-up, type of pedicle screw placement, incidence of complications, and type of complication. Finally, the management of screw-related complications is also discussed in detail.

Results

The literature review identified 130 possible relevant publications. After application of inclusion criteria, a total of 39 articles were selected for review: 1 randomized controlled trial, 8 case-control studies, and 30 case series (Table 1). Seven studies had different patient groups with alternative treatment options.[2–8,10,11,16,20,21,24–26,29–36,38,43,44,47,48,51,52,54,55,57,58,62–65] Thirteen studies were prospective, 25 were retrospective, and 1 study was both pro- and retrospective.[3] Seventeen studies reported a follow-up (mean follow-up 19.0 months, range 1–118 months). The 39 studies with a total of 46 study groups included 5654 patients with 35,630 pedicle screws inserted. The indication for surgery included a singular etiology for only 13 studies (trauma, 3; scoliosis, 5; degenerative, 4; and other, 1). The remaining studies included patients with multiple pathologies: degenerative (n = 27 of the reported 46 study groups), neoplasm (in 14 study groups), trauma (in 15 study groups), infectious (in 8 study groups), scoliosis (in 10 study groups), listhesis (in 10 study groups), and others (in 13 study groups). From 2 studies, the exact etiology was not apparent from the article.[48,64] Pedicle screw placement was performed free-hand in 11 studies, fluoroscopically guided in 16, navigated in 17, and robot-assisted in 2. Twenty-eight studies described the postoperative pedicle screw accuracy, with a mean percentage of 92.2% (range 67.8%–99.3%) being judged as correctly placed according to the authors. However, different classifications for pedicle screw accuracy have been used, making comparison between studies difficult.

Neurological complications were classified as dural lesions, nerve root irritation, or other neurological complication according to the authors' descriptions. Dural lesions were reported in 36 study groups, with a mean incidence of 0.18% per pedicle screw (range 0.0%–2.0%). Di Silvestre et al.[11] reported a dural lesion in 14 cases (12.2% of patients); all were asymptomatic. How many of all reported dural lesions led to a clinically significant complication was difficult to ascertain based on the available articles. A further analysis revealed that 9 patients in 5 studies suffered from a clinically relevant dural lesion (estimated incidence of 0.16% per patient [9 of 5654]).[2,3,36,44,47] A further analysis revealed 23 patients in 7 studies with a possible clinically relevant dural lesion (estimated incidence of 0.41% per patient [23 of 5654]). Irritation of a nerve root was reported in 32 study groups, with a mean incidence of 0.19% per pedicle screw (range 0.0%–4.0%). Amiot et al.[3] reported an irritation of a nerve root in 5 patients in their fluoroscopically guided patient group. On the other hand, Lonstein et al.[36] reported an irritation of a nerve root in 11 screws in 9 patients. Other neurological complications were reported in 6 studies, with an incidence of 0.04%–3.24% per pedicle screw. In 3 other study groups, the incidence of other neurological complications per pedicle screw could not be extracted from the article. One study reported 7 patients with sensorimotor deficits,[3] and another mentioned a patient with a partial bilateral foot drop.[25] The retrospective study by Devito et al.[10] reported neurological deficits in 4 cases that resolved after revision surgery without any permanent nerve damage. Altogether, 32 patients were reported in 10 studies to require further revision surgeries for misplaced pedicle screws causing neurological problems ranging from numbness to lower-extremity paraplegia.[2,3,10,29,36,43,44,47,55,57,58] None of the analyzed studies reported vascular complications, and only 2 studies reported visceral complications of clinical significance. One pleural effusion was reported by Di Silvestre et al.[11] (115 patients, 1035 thoracic pedicle screws). A pneumothorax was reported by Suk et al.[58] (462 patients, 4604 thoracic screws).

Only 3 authors reported intraoperative pedicle fractures. Di Silvestre et al.[11] reported pedicle fractures in 15 of 115 patients. Lonstein et al.[36] reported an intraoperative pedicle fracture in 0.1% of all screws and 0.2% of procedures, whereas Suk et al.[58] reported an intraoperative pedicle fracture in 0.24% of pedicle screws. The latter study is also the only one that reported screw fractures (0.5% of pedicle screws and 2.2% of procedures). Three authors reported on screw loosening or pullout. Stoffel et al.[57] reported 2 cases (of 100 patients), Wang and Mummaneni[62] reported 1 case (of 23 patients), and Suk et al.[58] reported 35 cases (of 462 patients). Wang and Mummaneni reported the only clinically relevant complication, with a S-1 screw pullout on postoperative Day 34 requiring a revision to extend the construct to the ilium.[62]

Discussion

The ideal pedicle screw should have a maximum diameter and length without breaching the pedicle's cortical layer or that of the vertebral body, and it should converge.[9] Nevertheless, a satisfactory outcome can also be achieved despite suboptimal screw placement and vice versa (Fig. 1). For example, a screw that just barely touches the lower border of the pedicle may cause a clinically apparent radiculopathy and it may require revision. On the other hand, a screw that lies inside the spinal canal may produce no symptoms at all. Scoring systems such as the one proposed by Gertzbein and Robbins[15] measure the cortical breach of a pedicle by a screw and are practical to compare technical methods in terms of accuracy, but have limitations. For example, a screw that lies in the inferior or medial border of the pedicle has a greater chance

TABLE 1: Publications analyzed*

Authors & Year	No. of Pts	No. of Pedicle Screws	Type of Screw Placement	FU (mos)	Accuracy (%)	Incidence (%)			No. of Revs	Clinically Relevant Screw-Related Complication
						Dural Lesion (per screw)	Nerve Root Irritation (per screw)	Other Neuro Complications (per screw)		
Amato et al., 2010	102	424	fluoro	8.0	92.2	0.47	0.47	1.70	7	2 pts w/ radicular pain & neuro deficits (improved completely after reop), 5 pts complained of radicular pain only
Amiot et al., 2000	100	544	fluoro	6.0	NR	0.00			7	4 pts w/ long-term neuro deficits (2 probably due to incorrectly placed screws); 5 pts had nerve root irritation, 7 pts had sensomotor deficit
	50	294	navig	NR	NR	0.00	0.00	0.00	0	
Arand et al., 2001	21	71	navig	NR	89.0	0.00	0.00	0.00	0	
Beck et al., 2009	95	414	FH	NR	78.0	0.00	0.00	0.00	0	
Bledsoe et al., 2009	34	150	navig	10.0	93.3	0.00	0.00	0.00	0	
Boachie-Adjei et al., 2000	50	282	FH	NR	NR	0.00	NR	NR	0	
Carbone et al., 2003	22	126	fluoro	10.0	NR	0.00	NR	NR	0	
Devito et al., 2010	635	3271	robot	NR	98.0	NR	NR	NR	NR	neuro deficits observed in 4 pts, following revisions, no permanent nerve damage encountered
Di Silvestre et al., 2007	115	1035	fluoro	48.0	NR		NR	NR	0	screw replacement in 5 pts (1 pleural effusion in only pt who was symptomatic w/ fever, 1 late loosening, 3 other); 14 pts had asymptomatic dural lesions
Girardi et al., 1999	35	330	navig	NR	NR	NR	0.00	0.00	0	
Iampreechakul et al., 2011	62	363	navig	NR	95.6	0.00	0.00	0.00	0	
Idler et al., 2010	85	326	navig	NR	98.5	0.00	0.00	0.00	0	
Karapinar et al., 2008	98	640	FH	42.2	94.2	0.00	0.00	0.00	0	
Katonis et al., 2003	112	658	FH	35.0	NR	NR	NR		0	1 pt had a neuro deficit (partial bilat drop foot after reduction of L4–5 spondylolisthesis that recovered completely after 6 wks)
Kim et al., 2004	394	3204	FH	NR	93.8	NR	0.00	0.00	0	
Kotani et al., 2007	25	81	fluoro	NR	89.0	NR	4.00	0.12	1	L-3 weakness & pain that resolved after screw removal
	20	57	navig	NR	98.2	NR	NR	NR	NR	
Kotil & Bilge, 2008	68	368	FH	NR	93.5	0.00	0.00	0.00	0	
Kuntz et al., 2004	29	209	fluoro	11.9	NR	NR	NR	0.00	NR	
Laine et al., 2000	50	277	fluoro	NR	86.6	0.00	0.00	0.00	0	
	41	219	navig	NR	95.4	0.00	0.00	0.00	0	
Lehman et al., 2007	60	1023	FH	NR	89.5	0.00	0.00	0.00	NR	
Lekovic et al., 2007	25	183	navig	NR	91.3	0.00	0.00	0.00	0	
Lim et al., 2005	78	231	navig	NR	95.5	2.00	0.00	0.00	0	
	35	231	navig	24.0	96.0	0.87	0.00	0.00	0	

(continued)

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Authors & Year	No. of Pts	No. of Pedicle Screws	Type of Screw Placement	FU (mos)	Accuracy (%)	Incidence (%)			No. of Revs	Clinically Relevant Screw-Related Complication
						Dural Lesion (per screw)	Nerve Root Irritation (per screw)	Other Neuro Complications (per screw)		
Lonstein et al., 1999	875	4790	fluoro	36.0	NR	0.10		NR	7	8 screws removed (resolving the neuro problem in 7), 1 pt w/ residual weakness; 11 screws in 9 pts caused nerve root irritation
Lotfinia et al., 2010	53	247	FH	6.0	67.8	NR	NR	3.24	NR	2 of 3 pts w/ neuro deficit had completely recovered motor or sensory function after screw replacement
Nakashima et al., 2009	67	150	navig	NR	92.7	2.00	0.00	0.00	0	
	67	150	fluoro	NR	84.7	0.00	1.00	0.00	1	
Nottmeier et al., 2009	220	1084	navig	6.0	92.5	0.18	NR	0.18	1	2 nerve root injuries w/o motor deficit, 1 of these pts had a permanent numbness in S-1 area, the 2nd had LE pain
Parker et al., 2011	964	6816	FH	NR	98.3	0.66	NR	0.04	3	3 symptomatic suboptimal screw placement: 1) LE paraplegia w/ sensory preservation, 2) progressive unilat LE numbness & weakness of quadriceps muscle, 3) unilat LE radicular pain w/ associated paresthesia, numbness, & weakness
Pechlivanis et al., 2009	31	133	robot	NR	93.5	0.00	0.00	0.00	0	
Rampersaud & Lee, 2007	24	204	fluoro	NR	96.0	0.00	0.00	0.00	0	
Ravi et al., 2011	41	161	navig	6.0	88.0	0.00	0.00	0.00	0	
Schnake et al., 2004	44	211	navig	NR	95.8	0.00	0.00	0.00	0	
	29	113	fluoro	NR	85.9	0.00	0.00	0.00	0	
Silbermann et al., 2011	30	152	FH	NR	94.1	0.00	0.66	NR	1	L-5 radiculopathy w/ pain & hypesthesia, revised on Day 2 postop; no residual symptoms
	37	187	navig	NR	99.0	0.00	0.00	0.00	0	
Stoffel et al., 2010	100	514	fluoro	15.0	NR	NR	NR	NR	3	
Suk et al., 2001	462	4604	fluoro	24.0	98.5	0.07	0.02	0.09	1	1 transient paraparesis due to delayed epidural hematoma because of medial perforation, 1 pneumothorax
Wang & Mummaneni, 2010	23	218	fluoro	13.4	NR	0.00	NR	NR	0	
Wang et al., 2010	32	268	FH	NR	85.0	0.00	0.00	0.00	0	
Wendl et al., 2003	30	141	navig	NR	99.3	0.00	0.00	0.00	0	
Youkilis et al., 2001	52	224	fluoro	NR	97.8	0.00	0.00	0.00	0	
Yue et al., 2002	32	252	fluoro	22.0	NR	0.00	0.00	0.00	0	

* Accuracy = percentage of screws regarded as correctly placed; FH = free-handed; fluoro = fluoroscopically guided; FU = follow-up; LE = lower-extremity; navig = navigated; neuro = neurological; NR = not reported; pt = patient; robot = robot-assisted; Revs = Revision operations due to neurological complications.



Fig. 1. Computed tomography scan from our own patient series showing a medially misplaced screw in the thoracic spine. In that case, the patient had a normal neurological examination, so the screw was not revised.

of producing neurological symptoms, but it will have the same grade as a screw that lies slightly superior or lateral. Thus, scoring systems should be regarded as a tool and not as a surrogate outcome measure. Therefore, the evaluation of successful fusion surgery should always include a clinical assessment in addition to an appraisal of screw position.

Nevertheless, the accuracy of screw insertion has become a frequent topic of recent publications on spine surgery.[23,28,30,36,44,59,61] A recent meta-analysis with 130 studies involving a total of 37,337 pedicle screws by Kosmopoulos and Schizas[28] found a mean misplacement rate of 8.7%. Furthermore, additional surgical procedures may be required to repair injuries related to screw problems, with a mean incidence of up to 20.8%.[41] Different techniques have been proposed to improve accuracy, including standard fluoroscopy guidance, computer or robotic assistance, navigation systems, or specific pedicle tools as PediGuard (Spine Vision SA).[32] The introduction of these techniques has led to a drastic reduction in screw misplacement rates, mainly in difficult cases such as scoliosis or revisions.[28]

Nonetheless, experienced spine surgeons have shown the ability to insert screws in the thoracolumbar region with a low incidence of screw misplacement simply by respecting the anatomical landmarks.[26] Furthermore, navigation or robotic systems present limitations related to calibration errors, bending of instruments, occasional blocking of the camera field of view, inadvertently touching/hitting reference frames, and nonrigid connection between the reference base and the actual surgical site. This review of the literature clearly shows that the accuracy rate of pedicle screws in thoracolumbar surgery is around 92.2%. However, the findings of this study confirmed that clinically relevant complications related to screw misplacement are very rare and occur in less than 0.5% of all procedures. This is in line with the findings from Lonstein et al.,[36] who reported in their meta-analysis of 4790 pedicle screws a breach rate of 5.1%, with no more than 0.2% of them causing neurological symptoms.

Management of Screw-Related Complications

As for every complication, the best treatment is prevention. Perfect anatomical knowledge, respect of all anatomical landmarks, careful evaluation of preoperative images, and use of modern systems of surgical assistance may reduce the risk of screw misplacement. Moreover, various methods (for example, intraoperative fluoroscopy, PediGuard, navigation systems, Spine Assist robot, and the O-Arm) can be used to confirm the pilot holes and the screw position during surgery. Furthermore, screw placement can be electrophysiologically checked during surgery by stimulating the pedicle probe or the screw and obtaining an electromyographic response peripherally. If this response occurs below the normal threshold for the intact cortical bone, it is highly probable that the screw is outside of the pedicle and needs to be replaced.[47] Although minor misplacement poses little risk of injury, a displacement greater than 4 mm is associated with a high risk of injury to vital structures depending on the instrumented level.[45]

Nerve Root or Spinal Cord Injury. The overall incidence of nerve root or spinal cord injury is rare, ranging between 0.6% and 11%.[40] Our study showed an overall mean incidence of dural lesions of 0.18% per pedicle screw and an overall mean incidence of nerve root irritations of 0.19% per pedicle screw (Fig. 2). Although a transitory self-limiting neurapraxia is more common, the incidence of a permanent neurological deficit is rare. Pihlajämaki et al.[50] found a permanent foot drop in 3 of 102 patients, which was only attributable to screw misplacement in 1 of the patients. A new neurological deficit or a new postoperative pain requires careful evaluation of postoperative images to rule out a conflict with a screw, in which case surgical revision is necessary. The planning of the revision procedure should be as complete and precise as possible, because a second misplacement will not be acceptable. A new trajectory within the pedicle should be planned, according to the previous entry point and the target. During the procedure, the misplaced screw is exposed and removed. In such cases, the application of intraoperative CT scanning or navigation is recommended. The new trajectory within the pedicle may create a larger hole, which may cause insufficient purchase of the subsequent screw. For such cases, a rescue procedure must always be available. The surgeon can choose either a larger salvage screw or skip the level and extend the fixation to more levels. Alternatively, the purchase can be augmented by means of PMMA injection. The cement may be injected into the new trajectory and the screw rapidly inserted before cement consolidation. Nowadays, several perforated screws exist that allow for PMMA injection. Recently, self-expanding screws have been developed as well, which increase screw purchase.



Fig. 2. Computed tomography scan from our own patient series showing a right medially misplaced screw in L-4, which caused new-onset radiculopathy. The symptoms completely disappeared after screw replacement.



Fig. 3. Computed tomography scan from our own patient series showing a left L-5 screw exceeding the ventral cortex of the vertebral body. Despite the close proximity to the iliac vessel, the patient was asymptomatic and the screw was not revised.

Vascular Injury. Although no vascular complications were reported in the reviewed studies, it is evident that several vascular structures are in danger during pedicle screw insertion: the azygos vein, intercostal artery, inferior vena cava, and aorta for the thoracic spine and mainly the aorta and common iliac vessels for the lumbar spine (Fig. 3). Immediate recognition of a vascular injury is mandatory, because it may be fatal for the patient. A direct vascular suture or embolization can be performed in emergency situations after corresponding repositioning. The need for replacement of a misplaced screw in tight contact with a vessel in an asymptomatic patient is controversial. Some authors consider the revision procedure too risky. Foxx et al.[14] found 33 of 680 inserted screws in the thoracolumbar region to be in contact with great vessels. None of the patients with vessel contact was noted to be symptomatic or presented with sequelae as a result of vessel contact. Other authors have suggested performing a revision procedure, because a secondary lesion may further develop into the site of contact between the screw and the continuously beating vessel (for example, lacerations and pseudoaneurysms). Klodell et al.[27] presented a case of safe revision for aorta impingement from a pedicle screw, which was diagnosed 1 year after a thoracic stabilization. Moreover, screw removal is not always technically simple and may be associated with major complications. Vanichkachorn et al.[60] presented a case of major vessel injury after removal of a distal screw fragment in the thoracolumbar region. They strongly encouraged a thorough evaluation for the indication to remove any distal screw fragment in a vertebral body. Lopera et al.[37] presented a series of 6 patients with 7 arterial injuries related to misplacement of fixation screws including the thoracic aorta (in 4 cases) and common iliac arteries (in 3 cases). There was wall penetration in 5 cases, contained penetrations in 2, and vessel occlusion in 1 case. Two patients had asymptomatic impingement of the aortic wall by the screws. One patient died and another underwent limb amputation. Three patients were treated with placement of stent grafts and screw removal. Screw replacement was performed in 1 patient. Conservative observation was done in 1 patient. They concluded that vascular injuries related to misplacement of fixation screws are potential life- and limb-threatening complications that require early recognition with prompt repair of vascular lesions and screw reposition.

Cerebrospinal Fluid Leak. If a CSF leak is seen during pedicle screw insertion, it means that the screw is too medial or inferior. In such cases, direct visualization by laminectomy is necessary to suture the leak, although some CSF leaks may spontaneously resolve.[13] The removal of a screw placed too medially into the neural canal is challenging because of potential neurological injury. Therefore, screw removal should always be done under direct visualization of the adjacent nervous structures. Donovan et al.[12] reported a case in which a screw was previously inserted into the canal with a CSF leak. They performed a durotomy and safely removed the screw under direct visualization of the neural elements. Nakashima et al.[43] reported the successful use of fibrin sealant to treat dural leaks after pedicle screw placement.

Visceral Injury. In this review, only 2 studies reported visceral complications that became clinically significant (see below). The proximity of thoracolumbar vertebral bodies and visceral organs may explain some visceral complications observed in the literature. A too long pedicle screw in thoracic region may potentially injure the esopha-

gus, the pleura, and the lung. O'Brien et al.[45] reported a case of esophagus impingement from pedicle screws at T-3. Esophagoscopy showed a discrete area of attenuation of the mucosa but no perforation. The authors revised the implant, inserting shorter screws in T3–5 levels bilaterally. Our literature review revealed only 2 visceral complications, notably a pleural effusion and a pneumothorax, that were reported after 35,630 pedicle screw placements in 5654 patients.

Pedicle Fracture. The overall pedicle breakage rate for lumbar fusion is around 1.1% in the literature.[13] In our study, only 3 authors reported intraoperative pedicle fractures.[11,36,58] This complication is the result of a mismatch between the screw size and the pedicle diameter (Fig. 4). Therefore, the right choice of screw size is mandatory, leaving the preoperative planning (pedicle diameter, pedicle angle, and screw length) of utmost importance. In young patients with a hard cancellous bone, tapping is recommended before screw insertion. Making the screw hole as large as the minor diameter of the inserted screw may avoid this complication. Once pedicle fracture occurs, the surgeon can choose an alternative method of fixation (for example, hooks) or incorporate additional levels into the fixation.

Screw Pullout. Screw pullout results from the loss of metal-bone interface integrity. Poor bone density (osteoporosis), excessive strain on the implant, residual sagittal imbalance, screw hole preparation technique, torque of insertion, screw purchase, and direction of screw placement may influence the pullout strength of pedicle screws. Tapping the screw hole or additional sublaminar hooks may increase pullout strength.[17] Once a screw pullout occurs, the surgeon should revise the implant. Different salvage techniques exist: using larger screws, screws with a larger thread depth and pitch, screws with bicortical purchase, milled bone graft impacted into the pilot hole, or PMMA-augmented screws. Restoring sagittal balance is mandatory to prevent new screw pullout.[46,49]

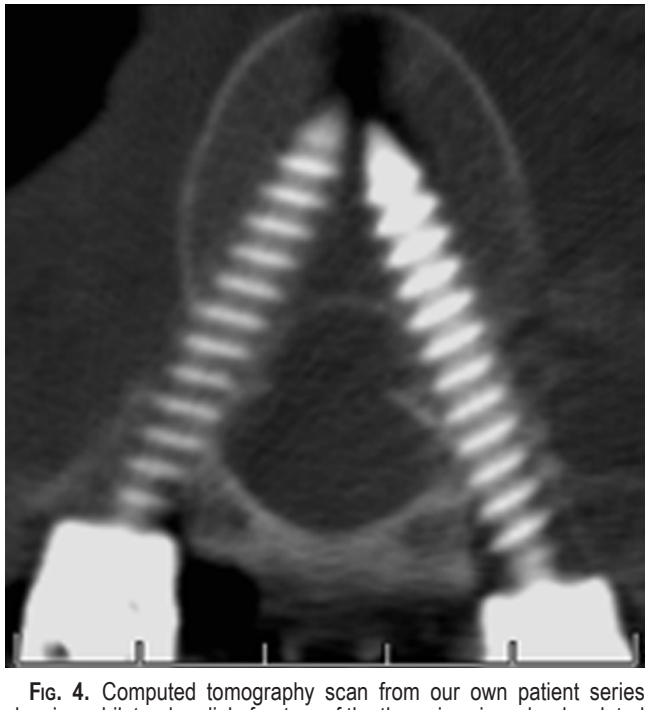


Fig. 4. Computed tomography scan from our own patient series showing a bilateral pedicle fracture of the thoracic spine, clearly related to the insertion of screws larger than the pedicles. In such case, no revision was done, because the screws were secured in the middle of the implant.

Screw Breakage. Screw breakage is mainly attributable to metal fatigue. Its incidence is reported to range from 3% to 5.7%,[40] and it often occurs at the interface between the screw and the rod. It often indicates a delay in fusion or pseudarthrosis. There is a clear trend for more screw breakage in fusions that include the sacrum, in patients in whom a spondylolisthesis was reduced without anterior support, and in incompletely instrumented or multilevel fusions.[22] In such cases, there is an absolute indication to revise the implant. The revision should correct the biomechanical reasons for breakage. The fusion strategy and the fixation extension should be reconsidered, and a successful union must be achieved. The constructs' stiffness may be improved by inserting anterior devices, by switching from titanium to stainless steel, or by inserting additional cross-links to the system.[46]

Late Spinal Instability. The presence of a misplaced screw may also lead to a loss of stiffness of the implant and to a late spinal instability. Açikbaş et al.[1] compared 2 groups of patients: Group A (16 patients) where the screw were correctly placed, and Group B (16 patients) where at least 1 of the screws was misplaced. They evaluated bone fusion, anterior height of the fractured vertebrae, and kyphotic deformity on neutral radiographs during the postoperative period and neutral/dynamic radiographs at the long-term follow-up. Group B presented with a minor degree of deformity correction in the postoperative period, a loss of correction on long-term radiographs, and more pain than patients in Group B. In conclusion, the impact of a misplaced screw on the implant stiffness should be always analyzed. Major misplacements in a critical part of the implant (for example, the ends of the implants and junctions) should be immediately corrected. In case of minor misplacement, close radiological and clinical follow-up is mandatory.

Conclusions

Pedicle screw placement is a safe procedure with a very low rate of clinically relevant complications. Navigation systems may be required in complex cases as revision procedures or scoliosis or in difficult spinal levels as the upper cervicothoracic spine. Although accuracy has been improved by introduction of different image guidance systems, the surgeon's knowledge of the anatomical landmarks, response to visual and tactile cues, and intraoperative decision making remain of paramount importance.

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: Tessitore, Gautschi, Schatlo. Acquisition of data: Gautschi, Schatlo. Analysis and interpretation of data: Gautschi. Drafting the article: all authors. Critically revising the article: Tessitore, Gautschi, Schaller. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Tessitore. Administrative/technical/material support: Tessitore, Schaller. Study supervision: Tessitore, Gautschi, Schaller.

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Manuscript submitted June 19, 2011.
Accepted July 21, 2011.

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Neurosurg Focus 31 (4):E9, 2011

Pedicle screw loosening in dynamic stabilization: incidence, risk, and outcome in 126 patients

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Object. The long-term outcome of lumbar dynamic stabilization is uncertain. This study aimed to investigate the incidence, risk factors, and outcomes associated with screw loosening in a dynamic stabilization system.

Methods. The authors conducted a retrospective review of medical records, radiological studies, and clinical evaluations obtained in consecutive patients who underwent 1- or 2-level lumbar dynamic stabilization and were followed up for more than 24 months. Loosening of screws was determined on radiography and CT scanning. Radiographic and standardized clinical outcomes, including the visual analog scale (VAS) and Oswestry Disability Index (ODI) scores, were analyzed with a focus on cases in which screw loosening occurred.

Results. The authors analyzed 658 screws in 126 patients, including 54 women (42.9%) and 72 men (57.1%) (mean age 60.4 ± 11.8 years). During the mean clinical follow-up period of 37.0 ± 7.1 months, 31 screws (4.7%) in 25 patients (19.8%) were shown to have loosened. The mean age of patients with screw loosening was significantly higher than those without loosening (64.8 ± 8.8 vs 59.3 ± 12.2, respectively; $p = 0.036$). Patients with diabetes mellitus had a significantly higher rate of screw loosening compared with those without diabetes (36.0% vs 15.8%, respectively; $p = 0.024$). Diabetic patients with well-controlled serum glucose (HbA1c ≤ 8.0%) had a significantly lower chance of screw loosening than those without well-controlled serum glucose (28.6% vs 71.4%, respectively; $p = 0.021$). Of the 25 patients with screw loosening, 22 cases (88%) were identified within 6.6 months of surgery; 18 patients (72%) had the loosened screws in the inferior portion of the spinal construct, whereas 7 (28%) had screw loosening in the superior portion of the construct. The overall clinical outcomes at 3, 12, and 24 months, measured by VAS for back pain, VAS for leg pain, and ODI scores, were significantly improved after surgery compared with before surgery (all $p < 0.05$). There were no significant differences between the patients with and without screw loosening at all evaluation time points (all $p > 0.05$). All 25 patients with screw loosening were asymptomatic, and in 6 (24%) osseous integration was demonstrated on later follow-up. Also, there were 3 broken screws (2.38% in 126 patients or 0.46% in 658 screws). To date, none of these loosened or broken screws have required revision surgery.

Conclusions. Screw loosening in dynamic stabilization systems is not uncommon (4.7% screws in 19.8% patients). Patients of older age or those with diabetes have higher rates of screw loosening. Screw loosening can be asymptomatic and presents opportunity for osseous integration on later follow-up. Although adverse effects on clinical outcomes are rare, longer-term follow-up is required in cases in which screws become loose.

(DOI: 10.3171/2011.7.FOCUS11125)

Key Words • **dynamic stabilization** • **Dynesys** • **screw loosening** • **osseointegration** • **diabetes**

Lumbar spinal arthrodesis is an accepted surgical option in the treatment of spondylosis to achieve stability and to eliminate pain. The indications for lumbar fusion include isthmic or degenerative spondylolisthesis, spinal stenosis with segmental instability, facet joint arthropathy, discogenic pain, iatrogenic destabilization, recurrent disc herniation, and spinal deformity.[5,26] There is broad discretion for each surgeon as to the specific approach, technique, and instrumentation to be used, despite large-scale randomized clinical trials.[27,28] With the advent of biologics and techniques, the fusion rates have increased;[6,15,16] however, a proportional improvement of the clinical outcome is unproven and remains anecdotal.[19]

A pedicle screw–based dynamic stabilization system aims to alter the mechanical loading of lumbar spinal motion segments. By unloading the disc and allowing a limited range of motion, the system theoretically provides needed segmental stability. Beneficial clinical outcomes

Abbreviations used in this paper: ODI = Oswestry Disability Index; VAS = visual analog scale.

associated with the Dynesys Dynamic Stabilization System (Zimmer Spine) have only been reported in small series.[8,12,21,24,25,29,30] Furthermore, the long-term outcomes and protective effects on adjacent-segment disease remains uncertain.[11,13,17]

One of the major concerns in dynamic stabilization is the incidence of screw loosening. Pedicle screws inserted without bone fusion may not hold against the weight-bearing forces of the human lumbar spine. Unlike arthrodesis, the durability of these dynamic constructs depends on both the anchoring of the pedicle screws and the material strength. Therefore, the long-term follow-up of and management strategies for screw loosening in patients in whom a dynamic stabilization has been used deserve more attention than conventional spinal fusion procedures.

In the present study we collected data in consecutive patients treated with the Dynesys Dynamic Stabilization System; the mean follow-up duration exceeded 3 years (37 months). The incidence of screw loosening and breakage was computed. Additionally, the risk factors and their effects on clinical outcomes were analyzed. This is the largest series in the literature of dynamic stabilization achieved with pedicle screws (a total of 658 screws) focusing on the management and outcome of loosened or broken pedicle screws.

Methods

Enrollment of Patients

The cases of consecutive patients who underwent posterior decompression and placement of a dynamic stabilization (Dynesys) system between September 2006 and May 2009 were retrospectively reviewed.

The surgical indications included symptomatic lumbar spinal stenosis, spondylolisthesis lower than Grade 1, recurrent disc herniation, and degenerative disc disease with discogenic pain associated with intractable radicular pain, back pain, or neurogenic claudication. The patients were considered candidates for surgery only if they had persistent symptoms refractory to conservative treatment for more than 4 months. This study was approved by the institutional ethics committee.

Surgical Technique

All surgeries were performed after induction of general anesthesia and with patients in a prone position of neutral lumbar lordosis with adequate cushioning. Two senior authors in the current study (H.C. and W.C.H.) performed all the procedures. Midline skin and fascia incisions were made for a standard laminectomy and foraminotomy. A medial partial facetectomy was performed in severe cases of foraminal stenosis to ensure that the exiting nerve root was adequately decompressed. Bilateral fascia incisions were then made for dissection through the intermuscular (Wiltse) plan. Under the guidance of intraoperative fluoroscopy, the Dynesys screws (closed-head, nonhydroxyapatite-coated, titanium alloy) were placed transpedicularly via the insertion point at the base of the transverse process without additional facet destruction. Special caution was taken to avoid pullback or reinsertion of the screws. The length and diameter of the screws were determined by preoperative CT scanning and confirmed intraoperatively. The polycarbonate urethane spacers were tailored for only slight distraction of the facet joints with independent measurement using the pedicle distance gauge. The spacers were then inserted together with the polyester cords following the standard technique. Two Exudrains were applied and maintained for 3 days.

Clinical Evaluation

The data were prospectively collected and retrospectively reviewed. Clinical outcome was assessed preoperatively and approximately 3, 12, and 24 months postoperatively. The assessment was performed by 2 special nursing assistants using the VAS for back and leg pain, as well as the ODI, under the supervision of the physicians.

Radiological Evaluation

Every patient underwent preoperative imaging, including plain and dynamic radiography, MR imaging, and CT scanning. Follow-up imaging included standard anteroposterior, lateral, and flexion-extension radiography at approximately 1, 2, 3, 6, 12, and 24 months after surgery. An initial halo sign (radiolucent line around the implant > 1 mm wide) followed by a double halo sign on later radiographs or CT scans was defined as screw loosening.[2,12,22] The measurement was performed using quantitative measurement analysis software (SmartIris, Taiwan Electronic Data Processing Co.). Radiographic interpretations, including halo sign and osseous integration, were made by independent radiologists and two neurosurgeons. For any ambiguity, CT scans were used for the final determination of halo sign and discussion to attain consensus.

Statistical Analysis

All statistical analyses were performed using the SPSS software (SPSS Inc.). Independent t-tests and paired t-tests were used for continuous variables, and the Fisher exact test was applied for categorical data. A p value of 0.05 was considered statistically significant.

Results

Of the 160 consecutive patients who underwent 1- or 2-level dynamic stabilization with Dynesys system, 126 patients (78.8%), in whom 658 screws were placed, completed the clinical and radiological evaluations for at least 2 years postoperatively. There were 72 men (57.1%) and 54 women (42.9%) whose mean age was 60.4 ± 11.8 years at the time of surgery (Table 1).

The mean clinical follow-up duration was 37.0 ± 7.1 months, and the mean radiological follow-up duration was 26.6 ± 7.4 months. In the 126 patients, 50 (39.7%) underwent a 1-level and 76 (60.3%) underwent a 2-level stabilization. The distributions of index levels were as follows: 1 (0.8%) at L2–3; 4 (3.2%) at L3–4; 35 (27.8%) at L4–5; 10 (7.9%) at L5–S1; 3 (2.4%) at L2–4; 58 (46.0%) at L3–5; and 15 (11.9%) at L4–S1 (Table 2).

Screw Loosening

Among the 658 screws, radiologically evident loos-

TABLE 1: Clinical and demographic characteristics*

Characteristic	Value (%)
no. of patients	126
sex	
male	72 (57.1)
female	54 (42.9)
mean age (yrs)	60.4 ± 11.8
mean follow-up (mos)	
imaging	26.6 ± 7.4
clinical	37.0 ± 7.1
no. of instrumented levels	
1	50 (39.7)
2	76 (60.3)

* Mean values are presented ± SD.

ening (identified by the presence of a halo sign and confirmed by double halo sign or CT scanning) was found in 31 screws (4.7%) in 25 (19.8%) patients.

The mean age of patients with screw loosening was significantly greater than that in younger individuals (64.8 ± 8.8 vs 59.3 ± 12.2, respectively; $p = 0.036$). The sex composition and the number of levels stabilized were not significantly different ($p = 0.897$ and $p = 0.674$, respectively) between patients with and without screw loosening. In patients with Type 2 diabetes mellitus, the rate of screw loosening was significantly higher than that in euglycemic patients (36.0% vs 15.8%, respectively; $p = 0.024$) (Table 3).

Among the 25 patients in whom screws loosened, 22 (88%) were identified within 6.6 months of surgery, whereas 3 were found at 9.5, 10.0, and 48.0 months. In 18 (72%) of the patients, the loose screws were located in the inferior level of construct, whereas in the other 7 (28%) the loose screws were seen in the superior level of the construct. None of the loose screws were found in the middle portion of construct in cases of 2-level stabilization.

Clinical Outcome

The overall clinical outcomes, measured by VAS (back and leg pain scores) and ODI, were significantly improved after surgery at 3, 12, and 24 months after surgery compared with status preoperatively. Furthermore, patients had significant improvement in VAS back, VAS leg, and ODI scores regardless of whether screw loosening was present or absent (Fig. 1).

TABLE 2: Distribution of treated levels

Instrumentation	Level	No. of Patients (%)
1 level*	L2–3	1 (0.8)
	L3–4	4 (3.2)
	L4–5	35 (27.8)
	L5–S1	10 (7.9)
2 levels†	L2–4	3 (2.4)
	L3–5	58 (46.0)
	L4–S1	15 (11.9)

* One-level surgery was performed in 50 patients (39.7%).
† Two-level surgery was performed in 76 patients (60.3%).

At the 24-months follow-up interval, the patients with screw loosening had significantly improved clinical scores of 3.4 ± 2.9, 2.1 ± 3.1, and 24.9 ± 19.5 (VAS back, VAS leg, and ODI, respectively) compared with preoperatively (6.1 ± 2.7, 7.0 ± 2.6, and 50.8 ± 17.7; $p = 0.001$, $p < 0.001$, and $p < 0.001$, respectively). Likewise, at 24 months postoperatively patients without screw loosening had significantly improved scores of 2.3 ± 2.6, 2.1 ± 2.8, and 21.7 ± 20.9 compared with preoperatively (6.4 ± 3.2, 7.1 ± 2.7, and 52.8 ± 18.7; $p < 0.001$, $p < 0.001$, and $p < 0.001$, respectively) (Table 3). The improvements were also significant at 3 and 12 months postoperatively ($p = 0.001$ and $p < 0.001$, respectively). There were no significant differences between the 2 groups at all evaluation time points (that is, preoperatively, and at 3, 12, and 24 months postoperatively; all $p > 0.05$) (Fig. 1).

Management of Loose and Broken Screws

There were 31 (4.7%) loose screws in 25 patients (19.8%) (Figs. 2 and 3) and 3 broken screws (0.46%) in 3 patients (2.38%) (Figs. 4 and 5). The comparison of patients with these problematic screw subgroups is demonstrated in Table 4. Due to the small numbers, statistical analysis was not performed.

In the 25 patients with postoperative screw loosening, it was regular follow-up radiography that identified the problem; there were no clinically relevant complaints. Because adverse effects were not apparent, none of the loose screws were removed. Continuous follow-up without intervention was exercised, and no further migration of the screws was documented. Surprisingly, 6 (24%) of the patients had remarkable radiographic improvement on later evaluations. The radiographic disappearance of a halo sign on later follow-up examinations was confirmed by CT, and therefore, osseous integration was indicated (Fig. 2). These 6 patients remained asymptomatic in a longer mean follow-up of 40 months. Conservative management was planned for patients in whom postoperative radiographs demonstrated a halo sign, unless further migration of screws or clinical deterioration indicated surgery.

The 3 patients in whom there was screw breakage have all been asymptomatic to date and continue to be followed up. Two of the broken screws were found in patients with screw loosening (Fig. 4), and the other one was noted in a patient without radiographically identified loosening (Fig. 5).

No revision surgery was performed for screw misplacement or neurological deterioration. However, 1 diabetic patient (0.79% in 126) suffered from wound infection and underwent surgery for debridement and removal of implants 28 months after the primary surgery.

Diabetes Mellitus and Screw Loosening

There were 25 diabetic patients (19.8%), all with Type 2 disease, in this series. Patients with diabetes had a significantly higher rate (36.0%) of screw loosening than patients with normal serum glucose (15.8%) ($p = 0.024$) (Table 3). For diabetic patients who underwent dynamic

TABLE 3: Comparison of data loosened screw and intact group*

Variable	Total	Screw Loosening (%)		p Value
		Yes	No	
no. of patients	126	25 (19.8)	101 (80.2)	
age (years)	60.4 ± 11.8	64.8 ± 8.8	59.3 ± 12.2	**0.036**
sex				0.897
male	72	14 (19.4)	58 (80.6)	
female	54	11 (20.4)	43 (79.6)	
level				0.674
1	50	9 (18.0)	41 (82.0)	
2	76	16 (21.1)	60 (78.9)	
serum glucose status				**0.024**
Type 2 DM	25	9 (36.0)	16 (64.0)	
euglycemia	101	16 (15.8)	85 (84.2)	
mean preop scores				
VAS back pain	6.3 ± 3.1	6.1 ± 2.7	6.4 ± 3.2	0.709
VAS leg pain	7.1 ± 2.7	7.0 ± 2.6	7.1 ± 2.7	0.868
ODI (%)	52.4 ± 18.4	50.8 ± 17.7	52.8 ± 18.7	0.625
mean 24-mo postop scores				
VAS back pain	2.5 ± 2.7	3.4 ± 2.9	2.3 ± 2.6	0.088
VAS leg pain	2.1 ± 2.9	2.1 ± 3.1	2.1 ± 2.8	0.962
ODI (%)	22.3 ± 20.6	24.9 ± 19.5	21.7 ± 20.9	0.519

* Mean values are presented ± SD. Bolded values indicate statistical significance. Abbreviation: DM = diabetes mellitus.

stabilization, the preoperative serum HbA1c (glycated hemoglobin) was significantly higher in cases involving loose screws than in those without screw loosening (8.92 ± 1.78 vs 7.31 ± 1.19, p = 0.018). Given an HbA1c of less than or equal to 8.0% as the cutoff value,[10,20] patients with well-controlled diabetes had a significantly lower chance of screw loosening (28.6% vs 71.4%, p = 0.021) than those with poorly controlled diabetes (HbA1c ≥ 8.1%) (Table 5).

Discussion

This study analyzed 658 screws used to place the Dynesys for dynamic stabilization in 126 patients with lumbar spondylosis. In a mean follow-up period of 3 years, 31 screws (4.7%) in 25 (19.8%) patients became loose. All the patients with loose screws were asymptomatic and identified radiographically during regular follow-up. Older age and diabetes were risk factors of screw loosening. The clinical outcomes were equally improved regardless of screw loosening. Due to the clinical silence, these patients were managed conservatively with continuous follow-up. In 6 (24%) of these patients with loose screws improvement of osseous reintegration was demonstrated on later radiographic studies during a mean follow-up period of 40 months. Therefore, nonsurgical management of these loose screws is a reasonable option in dynamic stabilization. This inference of management is opposed to a common belief underpinning the management of loose screws in a fusion construct, but it requires further study to corroborate. However, this report is the largest series to date of its type, and the radiographic improvement with osseous reintegration of these loose screws is reported for the first time in the literature of dynamic stabilization.

Screw loosening is an inherent issue in dynamic stabilization for lumbar spondylosis. In rigid fixation constructs the pedicle screws need to provide stabilizing strength only until bone fusion is achieved. A dynamic construct coupled with the bony interface, however, requires more long-term durability because no bone graft incorporation ever occurs. Therefore, the longer the follow-up period, theoretically the higher the rate of screw loosening will be. Furthermore, screw loosening in static constructs is often related to pseudarthrosis requiring revision. Excess loading in a rigid fixation without bone fusion may cause implant breakage. Dynamic constructs, however, are designed to shift rather than bear the entire loading of the lumbar spine. The cost of this flexibility is the need for more material strength and anchoring force at the interface. In the present study, we have demonstrated that loose screws in a dynamic stabilization construct can be asymptomatic and there is a chance of bone regrowth.

There are several series involving the Dynesys system with different incidences of screw loosening. Stoll et al.[25] reported on 10 loose screws (3.6%) in 8 (11%) of 73 patients at a mean follow-up of 38 months, and one patient underwent revision surgery at 14.5 months postoperatively. Grob et al.[8] reported on screw loosening in 4 (13%) of 31 patients at the 2-year follow-up, and 2 of these patients underwent reoperation. Welch et al.[29] documented 1 loose screw in 101 patients at the 1-year follow-up. Würgler-Hauri and colleagues[30] noted 2 loose screws and 4 broken screws in 36 patients at the 1-year follow-up.

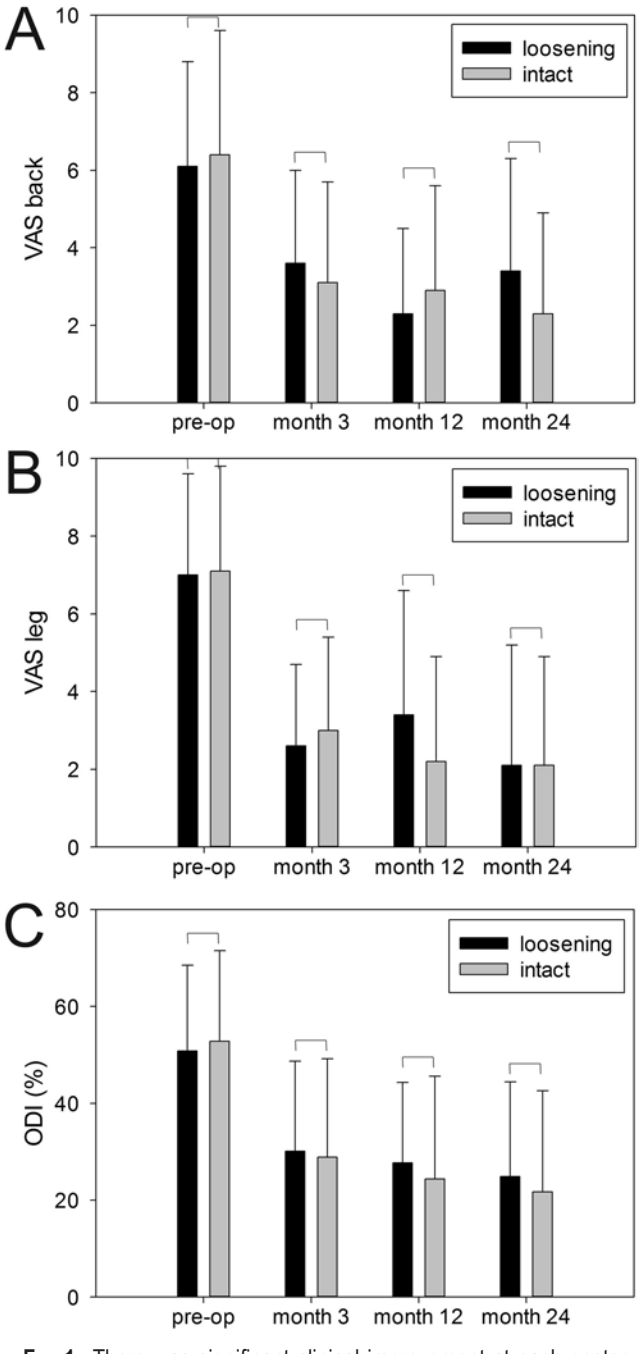


Fig. 1. There was significant clinical improvement at each postoperative evaluation time point compared with preoperative status. There were no statistical differences between patients with and without screw loosening at all evaluation time points: VAS for back pain **(A)**; VAS for leg pain **(B)**; and ODI **(C)**.

Schnake et al.[24] reported 4 (16. 7%) of 24 patients with 4 loose screws (4.2%), including one that was broken, at the 2-year follow-up. Schaeren and coworkers[23] observed no new case of implant failure between 2 and 4 years in the continuous follow-up of 19 patients in the same series. In a mean follow-up period of 54 months, Di Silvestre et al.[3] reported 4 (13.8%) of 29 patients treated for degenerative scoliosis with asymptomatic screw loosening. Our group reported a screw loosening rate of 19.7% (14 of 71 patients) and 4.6% (17 of 368 screws).[12] Most of the rates reported for screw loosening range from 10% to 20% of the patients and seldom require revision surgery. This feature of dynamic stabilization is distinct from arthrodesis series, in which screw loosening occurs at a lower rate but often causes pseudarthrosis warranting reoperation.[4,18,31]

The etiological and risk factors of the screw loosening in dynamic stabilization are not extensively addressed in the literature. In a previous report, age greater than 55 years has been proposed as a risk factor without adverse effects on clinical outcomes.[12] In the present study, the mean age of patients with loosened screws was 5.5 years older than that in patients without screw loosening (64.8 ± 8.8 vs 59.3 ± 12.2, respectively; $p = 0.036$). Differences in sex and 1- or 2-level constructs were not significant between cases involving loose screws and those not involving them. Because patients with inadequate bone density should not be considered candidates for dynamic stabilization, patient age may be of importance as it might correlate with decreased bone mineral density.

The data in this study warranted serum glucose control prior to implantation of the dynamic stabilization system. Diabetic patients are at higher risk of screw loosening (36.0% vs 15.8%, respectively; $p = 0.024$) than nondiabetic patients. Furthermore, patients with better-controlled diabetes (HbA1c ≤ 8.0%) preoperatively had a significantly lower rate of screw loosening (28.6% vs 71.4%, respectively; $p = 0.021$). Additionally, disease status in the 2 diabetic patients with loose screws and osseous reintegration was also well controlled (Table 4). Hyperglycemia in patients is reported to cause reduced bone formation and diminished mechanical strength of newly formed bone.[1,7,9,14] Osseous integration between implant and host bone interfaces has been extensively studied in dental surgery but seldom addressed in the spine literature.[10,20]

More loose screws were identified in the lower vertebral body of the construct than the upper (72% vs 28%, respectively). In particular, in 2-level stabilization constructs, none of the loose screws were found in the middle vertebral body. This finding is consistent with several other reports of the Dynesys system. Stoll et al.[25] reported that in all cases with loose screws, the most cranial and/or the most caudal screws were involved. Di Silvestre et al.[3] noted that asymptomatic radiolucent lines found in 4 patients were all around the S-1 screws. This is indirect biomechanical evidence to suggest that marginal segments of the dynamic construct share more load during movement. The lower end of the construct is at higher risk of screw pullout, which deserves more caution in surgical planning and execution.

The actual timing of the occurrence of screw loosening is uncertain. The majority (88%) of the loose screws in the present study were found within 6.6 months of surgery, and the remaining 3 cases were at 9.5, 10.0, and 48.0 months. Similar findings have been reported by Stoll et al.,[25] in whose series most loose screws appeared in the early postoperative period (< 6 months), and none appeared later than 1 year. In a 4-year follow-up study of Dynesys system–treated patients, Schaeren and colleagues[23] found no new case of screw loosening between

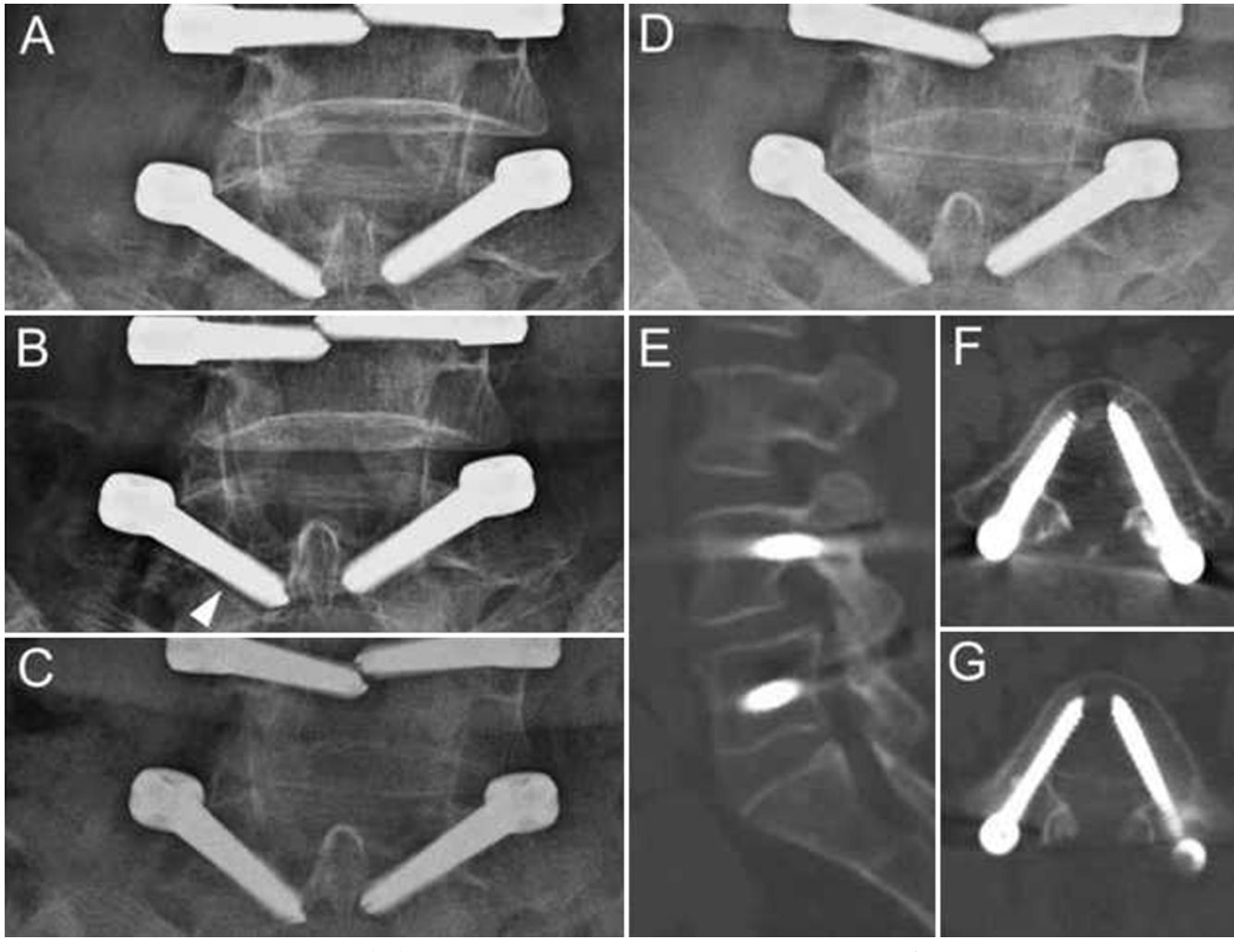


Fig. 2. Representative case of a 67-year-old woman who underwent dynamic stabilization at L4–5, and in whom a loosened right L-5 pedicle screw (**B,** *arrowhead*) was documented 5 months postoperatively. There was no clinical deterioration. **A–D:** Radiographs obtained at 1, 5, 17, and 33 months after surgery, respectively. Osseous integration and filling of the previously loosening tract around the screw were demonstrated on radiographs at 17 **(C)** and 33 **(D)** months postoperatively. **E–G:** Reconstructed CT scans acquired 33 months postoperatively (sagittal view, L-4 level; axial views, L-5 level).

2 and 4 years. In the current series, we identified only 1 case of delayed-onset loosening (bilateral L-4 pedicle screws) in addition to the preexisting bilateral S-1 pedicle screws mentioned earlier. The frequent early-onset screw loosening may indicate that poor implant–host bone osseous incorporation is caused more by medical conditions (for example, age, osteopenia, cigarette smoking, diabetes, or steroid use). Additionally, loosening of the implant can depend on surgical techniques of screw insertion. However, screw loosening is multifactorial and these inferences need future investigation for corroboratation.

The indication for dynamic stabilization is a caveat of this series. The authors still advocate static constructs with interbody bone grafts for patients with obvious spinal instability causing mechanical back pain. Any patient with spondylolisthesis of Grade 1 or higher is not considered a candidate for the dynamic stabilization. We tend to use the dynamic construct for younger patients who have undergone repeated discectomies or wide partial facetectomies, but there is a gray zone between arthrodesis and decompression alone of the lumbar spine. At times, restriction rather than elimination of the motion of the lumbar spine may be sustainable. Although most of the patients in the present series had satisfactory outcomes, our study does not provide sufficient data to support the optimal indications of the dynamic stabilization device. Future studies with stratification of each specific indication for the dynamic stabilization device are necessary to clarify its optimal application.

There are limitations to this study. This cohort was composed of patients with lumbar spondylosis of various kinds, including unstable stenosis, degenerative disc disease, mild spondylolisthesis, recurrent disc herniation, and iatrogenic instability. The surgical indications for dynamic stabilization in the study were not uniform, which might contribute differently to screw loosening. The length and diameter of screws were not analyzed. Cigarette smoking, bone quality, and body mass index may also have been confounding factors. The risk factors were not fully disclosed. Moreover, the actual time of occurrence of the

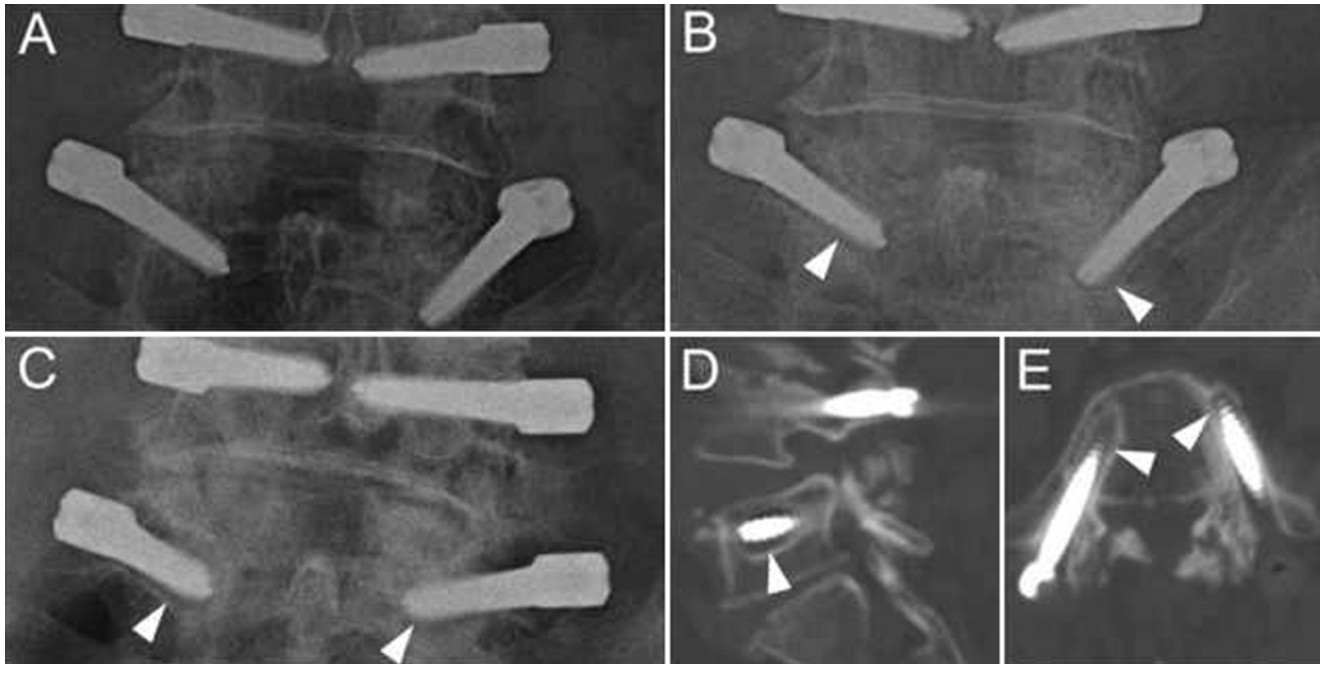


Fig. 3. Representative case of a 70-year-old man who underwent dynamic stabilization at L4–5 and in whom screw loosening occurred bilaterally at the L-5 pedicles (**B–E,** *arrowheads*) 3.5 months after surgery. These screws remained loose at 18 months postoperatively and asymptomatic. **A–C:** Radiographs acquired 1, 3.5, and 18 months postoperatively, respectively. **D and E:** Sagittal and axial CT scans acquired at 18 months after surgery.

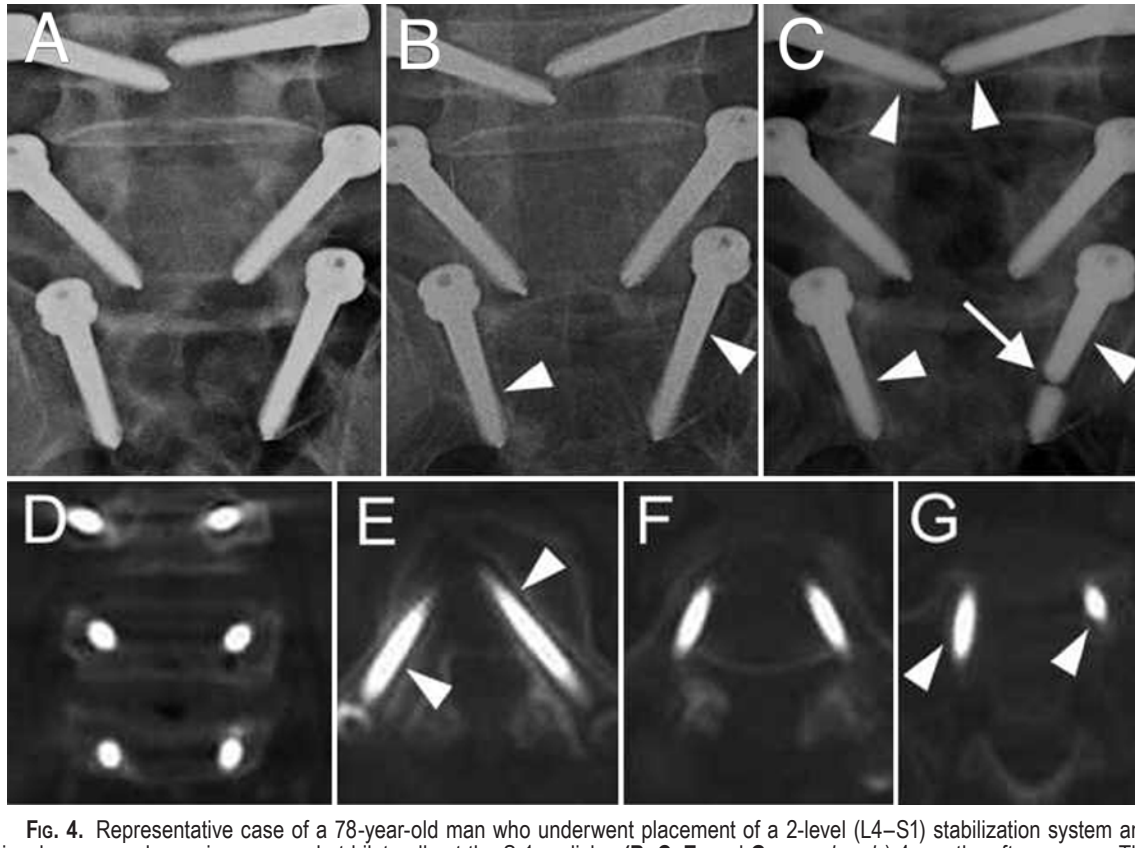


Fig. 4. Representative case of a 78-year-old man who underwent placement of a 2-level (L4–S1) stabilization system and in whom screw loosening occurred at bilaterally at the S-1 pedicles **(B**, **C**, **E**, and **G**, *arrowheads*) 4 months after surgery. The screws remained loose and the left S-1 screw was found to be broken (**C**, *arrow*) 28 months postoperatively, although the patient experienced no symptoms. At the same time, bilateral L-4 pedicle screws were also noted to be loose *(arrowheads).* **A–C:** Radiographs acquired 2, 4, and 28 months after surgery, respectively. **D–G:** Reconstructed CT scans obtained 28 months postoperatively (coronal, L-4; axial, L-5; axial, S-1).

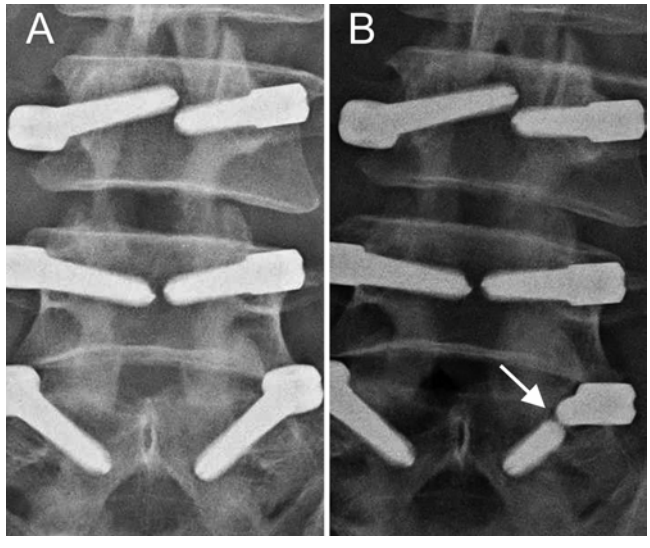


Fig. 5. Representative case of a 34-year-old man who underwent placement of a 2-level (L3–5) stabilization system and in whom the left L-5 pedicle screw broke (**B,** *arrow*) 24.5 months after surgery without clinical symptoms. **A and B:** Radiographs acquired 1 and 24.5 months postoperatively, respectively.

screw loosening was earlier than that caught on imaging studies due to clinical silence. The true effect on clinical outcomes can only be determined by longer follow-up. The in vivo elasticity and durability of the dynamic constructs are uncertain.

TABLE 4: Summary of data in 26 patients with problematic screws

Variables	Initial Radiographic Halo Sign*			Initially Solid
	Osseous Integration	Persistent Halo Sign	Broken Screw	Broken Screw†
no. of patients	6	17	2	1
age (yrs)	64.5	64.0	73.0	34.0
sex				
male	3	9	2	1
female	3	8	0	0
instrumented levels				
1	4	5	0	0
2	2	12	2	1
serum glucose status				
Type 2 DM	2	7	0	0
euglycemia	4	10	2	1
screw location				
top	1	6	0	0
bottom	5	11	2	1
1st identified (mos)	4.1	4.6	3.3	24.5
imaging follow-up (mos)	40.0	24.8	27.9	24.5

* Indicates screw loosening.

† One patient had a broken screw that had no halo sign of loosening on the initial radiographs until 24.5 months postoperation.

TABLE 5: Screw loosening in 25 patients with diabetes*

HbA1c at Op	Screw Loosening		Loosening Rate	p Value
	Yes	No		
no. of patients	9	16		
≥8.1 %	5	2	71.4%	**0.021**
≤8.0 %	4	14	28.6%	
mean ± SD	8.92 ± 1.78	7.31 ± 1.19		**0.018**

* Mean values are presented ± SD. Bolded values indicate statistical significance.

Conclusions

Screw loosening in dynamic stabilization is not uncommon (4.7% of screws in 19.8% patients). Older age patients or those with diabetes have higher rates of screw loosening. Screw loosening can be asymptomatic and have a chance of osseous integration on later follow-up. Although there were few adverse effects on clinical outcomes, longer-term follow-up is required to examine the impact of loosened screws.

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: JC Wu, Tu. Acquisition of data: JC Wu. Analysis and interpretation of data: Tsai, CL Wu. Drafting the article: Tsai, CL Wu. Critically revising the article: Ko, Tu. Reviewed submitted version of manuscript: Ko, JC Wu, Tu. Approved the final version of the manuscript on behalf of all authors: Ko. Statistical analysis: Tsai. Administrative/technical/material support: Huang, Cheng. Study supervision: Huang, Cheng.

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Manuscript submitted June 11, 2011.
Accepted July 18, 2011.

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Neurosurg Focus 31 (4):E10, 2011

Complications related to instrumentation in spine surgery: a prospective analysis

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Object. Prospective examination of perioperative complications in spine surgery is limited in the literature. The authors prospectively collected data on patients who underwent spinal fusion at a tertiary care center and evaluated the effect of spinal fusion and comorbidities on perioperative complications.

Methods. Between May and December 2008 data were collected prospectively in 248 patients admitted to the authors' institution for spine surgery. The 202 patients undergoing spine surgery with instrumentation were further analyzed in this report. Perioperative complications occurring within the initial 30 days after surgery were included. All adverse occurrences, whether directly related to surgery, were included in the analysis.

Results. Overall, 114 (56.4%) of 202 patients experienced at least one perioperative complication. Instrumented fusions were associated with more minor complications ($p = 0.001$) and more overall complications (0.0024). Furthermore, in the thoracic and lumbar spine, complications increased based on the number of levels fused. Advanced patient age and certain comorbidities such as diabetes, cardiac disease, or a history of malignancy were also associated with an increased incidence of complications.

Conclusions. Using a prospective methodology with a broad definition of complications, the authors report a significantly higher perioperative incidence of complications than previously indicated after spinal fusion procedures. Given the increased application of instrumentation, especially for degenerative disease, a better estimate of clinically relevant surgical complications could aid spine surgeons and patients in an individualized complication index to facilitate a more thorough risk-benefit analysis prior to surgery. *(DOI: 10.3171/2011.7.FOCUS1134)*

Key Words • **spine surgery** • **complication** • **adverse event** • **fusion** • **instrumentation**

Given the impact of patient diagnosis and individual pathological entities, spine surgeons must remain critical when determining the indications for the use of instrumentation in spinal procedures. Several recent evaluations of administrative databases have revealed increases in the rates of spinal fusions.[9,16,24] In the cervical spine, one group of authors noted a 206% increase in the rate of fusions performed in the Medicare population from 1992 to 2005.[24] The Nationwide Inpatient Sample, in a review from 1990 to 2000, revealed a 90% increase in the rate of cervical surgeries performed in the general adult US population.[19] Similar studies investigating the use of instrumentation in Medicare patients with lumbar stenosis affirmed that rates of fusion increased 3.6-fold from 1992 to 2003,[25] whereas complex fusion surgery increased 15-fold from 2002 to 2007.[9] Given the increase in the number and complexity of spine fusions, the contributions of these procedures to overall complications are of greater consequence to collective clinical outcomes.

The results of mining data from several administrative databases have been presented in the literature in an attempt to quantify the relationship between complication prevalence and spinal fusions in a large sample.[3,9,14,23] These large retrospective evaluations are entirely based on billing codes during inpatient hospitalization and discharge. When evaluating perioperative complications, a prospective evaluation by a direct observer may decrease selection and recall biases, offering a more accurate assessment of perioperative adverse events. In a recent review of retrospective and prospective complications in spine surgery, the authors demonstrated a consistent underreporting of complications in retrospective studies.[18]

Few studies offer an unambiguous examination of perioperative complications through prospective study. The majority of prospective assessments in the spine literature are industry-sponsored device trials that limit their assessment to specific spinal implants in carefully selected surgical patients.[1,12,21] Prospective studies using an easily replicated complication definition while focusing on the complication incidence after spine surgery are limited.

Abbreviation used in this paper: LOS = length of stay.

We performed a prospective study of patients undergoing spinal surgery at a tertiary care facility. An easily reproducible complication definition was based on a prospective survey of spine surgeons and validated through parallel assessment of patients who underwent spinal surgery.[20] Based on the survey results, all adverse medical events were included in the assessment (typically as minor complications). An independent auditor graded all complications. In this report, the primary analysis was performed to identify the impact of fusion on the perioperative complication incidence.

Methods

All elective and emergency cases to the Thomas Jefferson University Hospital neurosurgery spine service were suitable for study admission. The institutional review board of Thomas Jefferson University approved data collection for this study from May 2008 until December 2008. In this period, 248 consecutive patients who underwent cervical, thoracic, and lumbar surgery were entered into the study and prospectively followed up by an independent auditor (J.M.) with extensive experience in pre- and postoperative care of spine surgery patients. Of this overall cohort, 202 patients had instrumentation placed at a minimum of 1 level, and their cases are further analyzed in the present study. To preserve the prospective nature of this study, data in any patient unable to be enrolled initially on presentation by the auditor were not considered for analysis. Complication grading was confirmed by a secondary auditor not directly involved in patient care. All patients were closely followed throughout their hospital stays and during an initial 30-day postoperative period. To capture any postdischarge perioperative complications, all postoperative care and patient follow-up appointments were completed at a single point of service. Demographic information, diagnosis, surgical approach, levels and type of decompression and/or fusion, type and number of complications, body mass index, and LOS were entered prospectively into a central database. Prior to initiation of the study, a list of common spinal complications was compiled and used for prospective identification.

Major and minor complications were defined based on the methodology and results of a previously validated study.[20] The definition of a complication used in this study was broad and included all perioperative medical adverse events, which were most often classified as minor complications (Table 1). Major complications were defined as events responsible for permanent sequela(e) or requiring further intervention, such as reoperation. All events with transient detrimental effect (including medical adverse events) or surgical complications with limited need for further intervention were deemed minor. Results were prospectively recorded and maintained by the primary auditor (J.M.).

Statistical evaluation was performed using the JMP statistical package (version 7.02, SAS Institute, Inc.). Associations between complication incidence and fusion were detected using logistic regression analysis followed by chi-square comparisons. The presence of a relationship between thoracic/lumbar fusion and complications was evaluated using the Wilcoxon signed-rank test. Chi-square tests were employed to assess the impact of the complication, revision surgery, and patient obesity on complication incidence. For comparisons of complication incidence and approach or diagnosis, a chi-square test was used. Specifically, we employed the likelihood-ratio chi-square statistic because many of these individual cells have low expected values. Survival analysis was performed to evaluate the effect of complications on LOS in the fusion subset.

Results

In the entire survey, 248 patients with a variety of spinal pathological entities were assessed. For this subanalysis, 202 patients underwent spinal fusions and the results were examined (Table 2). In the fusion cohort, the mean patient age was 56.1 years, and there were 95 female and 107 male patients. The mean body mass index was 29.3. In this subset of the study population, 113 patients (55.9%) underwent cervical spine surgery, whereas 89 (44.1%) underwent thoracic, thoracolumbar, or lumbar fusion. Forty-nine patients (24.3%) underwent a revision procedure.

TABLE 1: Classification of major and minor perioperative complications in spine surgery*

Major Complication	Minor Complication
periop event producing a detrimental effect or requiring significant further intervention including reop; also includes some severe MAEs occurring in the periop period	periop event producing only transient detrimental effect, w/o requiring further intervention; includes most MAEs in the periop period
stroke	excessive blood loss requiring transfusion
deep wound infection	C-5 palsy after cervical laminectomy
pulmonary embolism	transient dysphagia
hardware/graft malposition requiring reop	arterial line infection
sepsis	post urinary tract infection
pneumonia w/ tracheostomy	superficial wound infection
myocardial infarction	deep venous thrombosis
postop myocardial infarction	pneumonia
death	urinary retention

* MAE = medical adverse event.

TABLE 2: Summary data in 202 patients undergoing spinal fusion

Variable	No. of Cases (%)*
no. of patients	202
mean age (yrs)	56.1
cervical	113 (55.9)
thoracic, thoracolumbar, & lumbar levels	89 (44.1)
females	95 (47.0)
males	107 (53.0)
mean body mass index	29.3
mean no. of fusion levels	3.3
revision op	49 (24.3)
approach	
anterior	47 (23.3)
posterior	83 (41.1)
anterior-posterior	72 (35.6)
diagnosis	
degenerative	132 (65.3)
trauma	39 (19.3)
tumor	16 (7.9)
infection	15 (7.4)

* Unless otherwise indicated.

Indications for surgical treatment varied. In the subset of patients undergoing fusion, underlying pathological entities requiring operative intervention were most often degenerative in nature (132 [65.3%] of 202). Traumatic injuries were documented in 19.3% of the subset (39 cases). Neoplasm resection was performed in 16 patients (7.9%), and infectious processes were present in 15 (7.4%). The 3 most common procedures were posterior cervical decompression, anterior cervical decompression, and anterior-posterior lumbar decompression, all with fusion. An anterior approach to the pathological entity was used in 47 patients (23.3%), an isolated posterior approach in 83 (41.1%), and a combined anterior-posterior approach in 72 (35.6%).

Of the total cohort of 248 patients, 202 (81.5%) underwent a spinal fusion. Patients in whom an instrumented fusion was performed were statistically more likely to have overall complications (114 of 202 patients; $p = 0.0024$). In cases of cervical spine pathology, the majority of procedures were instrumented fusions (95.0%) and the mean number of instrumented vertebral was 3.0 per patient. In the thoracic, thoracolumbar, and lumbar regions, 69.5% of patients underwent instrumented fusion covering a mean of 3.4 levels. Further analysis into these localized cohorts revealed no association between cervical fusion and complications, but there was a significant correlation between complications and thoracic and lumbar fusions for minor, major, and all complications ($p = 0.0001$, $p = 0.0232$, and $p = 0.0001$, respectively).

Of these 202 fusion-treated patients, the overall complication rate was 56.4%. Patients undergoing a tumor resection and fusion were more likely than patients with other pathological entities to sustain a complication ($p = 0.006$, chi-square test) (Fig. 1). Furthermore, the anterior-

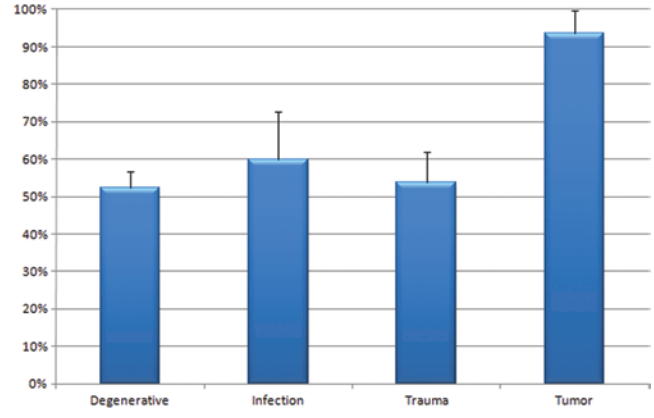


Fig. 1. Postfusion incidence of complications stratified by diagnosis.

posterior approach was associated with more complications than either the anterior or posterior approach alone ($p = 0.0006$) (Fig. 2). The number of segments fused in the cervical spine did not result in a significant increase in complications. However, in the thoracic and lumbar spine, Wilcoxon signed-rank testing revealed significant correlation between the number of levels fused and the overall complication rate ($p = 0.0003$ and $p = 0.0041$, respectively).

Length of stay ranged from 1 to 69 days. The median LOS for patients without complications was 5 days, whereas for patients with complications the median LOS extended to 10 days. In this cohort, patients with a minimum of 1 complication had a significantly longer LOS ($p < 0.0001$, Wilcoxon signed-rank test) (Fig. 3).

These results were also analyzed for additional variables that have been hypothesized to increase complication incidence. Advanced age (> 65 years) correlated with an increased risk of complications ($p = 0.006$). Despite the increased technical difficulty involved in revision procedures, the incidence of complications was not statistically increased. Comorbidities such as hypertension, diabetes mellitus, cardiac disease, and other systemic entities were evaluated with multivariate analysis to determine any correlation with perioperative complications. The presence of each of these factors was found to be associated with a higher rate of complications ($p = 0.0199$, $p = 0.0222$, $p = 0.0284$, and $p < 0.0001$, respectively).

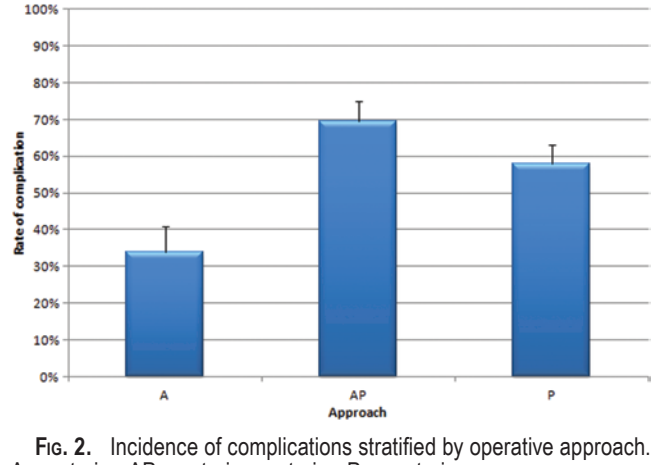


Fig. 2. Incidence of complications stratified by operative approach. A = anterior; AP = anterior-posterior; P = posterior.

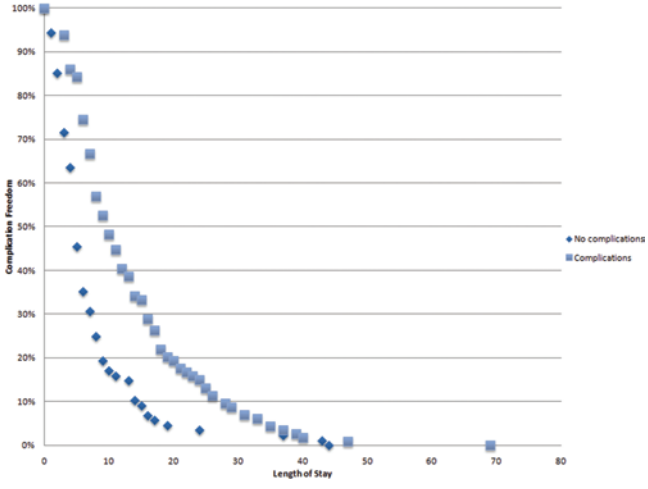


Fig. 3. Kaplan-Meier curve depicting the results of the LOS analysis.

The most common major complication was deep wound infection requiring operative wound debridement. The most common minor complications were urinary tract infection and dysphagia (Table 3). There were 2 deaths. One patient died of pulmonary complications after an instrumented fusion for an occipitocervical dislocation. In the other case, after undergoing decompression and fusion for a metastatic lesion to the thoracic spine, a 62-year-old patient with widely metastatic cervical cancer died on postoperative Day 4 after another a lesion in the spleen resulted in a fatal hemorrhage.

TABLE 3: Most common major and minor complications after spine fusion

Complication	Incidence (%)
major	
deep wound infection	11.4
new neurologic deficit	4.0
sepsis	3.6
hardware/graft malposition	2.0
myocardial infarction	2.0
pulmonary embolism	2.0
death	1.0
pneumonia w/ tracheostomy	0.5
minor	
urinary tract infection	13.4
dysphagia	8.8
deep venous thrombosis	7.4
pneumonia	5.9
urinary retention	4.9
hyponatremia	3.0
excessive blood loss requiring transfusion	3.0
durotomy	2.5
pneumothorax	2.0

Discussion

There is currently no consistent definition of what constitutes a complication or adverse event in the spine surgery literature. The authors of some series have described postoperative dysphagia as an inevitable result of anterior cervical fusion and not necessarily a complication, whereas others have included this as a minor complication in their reporting.[2,11,22] To perform any meaningful comparison of outcomes after spinal surgery, numerous centers must be able obtain and record relevant complication data in a standardized and reproducible manner.[10] In the present study, we performed a prospective observational analysis using an easily reproducible grading system of complications previously validated by spine surgeons and spine surgery patients.[20] A comprehensive, ideal system for complication analysis would include this graduated complication severity score in addition to a patient-specific comorbidity profile.[7] Ultimately, this approach would allow patient comorbidities and procedural complexity to be integrated for the purpose of the development of a procedure-specific, risk-adjusted predictive model for complications in spinal surgery.[7,17]

In the analysis of a large retrospective database, Wang, et al.[23] reviewed the Nationwide Inpatient Sample database and reported rates of complications after fusions from 9.02% to 10.5%, compared with an overall prevalence of 3.93% in nonfusion cases. Additionally, Deyo et al.[8] reviewed a Medicare database and determined a complication rate 1.9 times greater in fusion-treated patients than in those who had undergone decompression alone and, more recently,[9] noted an 2.95-fold increase in life-threatening complications after complex fusions compared with decompression alone. Complication incidences derived from prospective evaluations are typically directed at specific surgical procedures or noninferiority analyses of certain spinal implants; prospective assessments of complication incidence in broader patient populations are limited.[29] One of the prospective randomized Spine Patient Outcomes Research Trials (SPORT) prospectively evaluated the complication incidence of 372 patients who underwent surgical correction for spondylolisthesis.[26] These authors reported a 30.8% incidence of early and late complications. In a similar retrospective study,[14] however, another author group evaluated 66,000 patient records in the Nationwide Inpatient Sample administrative database of patients undergoing fusion for the same disease process; they reported an 11% rate of complications. In the present study, a minimum of 1 complication occurred in 56.4% of patients, with an increased likelihood of complication with an increasing number of levels fused. Furthermore, advanced age and comorbidities such as hypertension, diabetes mellitus, cardiac disease, and systemic disease significantly increased the complication rate. Based on these data, future research efforts to define a complication impact scale should concentrate on multicenter prospective observational trials with a large diversified patient cohort.

The methodology employed in this analysis presents several issues. The use of instrumentation was associated with more complications than decompression alone ($p = 0.0024$). Complications and their association with an operative approach, surgical indication, and other comor-

bidities have been reported in separate manuscripts.[4–6,27,28] However, the rate of overall complications is higher in the present series than many others that retrospectively evaluated perioperative complications after spinal fusion. The prospective design of our investigation relied less on the medical record and recall of the investigators and more on the accumulation of essential clinical details prospectively throughout the patient's hospital course; a recent review confirmed that prospective studies identified a statistically higher incidence of complications.[18] Loss to follow-up was a potential source of bias in this observational cohort. Most operations were complex spinal cases (24.2% revisions) often treated with a combined (anterior-posterior) approach (35.6%) and multilevel fusion (mean 3.3 levels). Because ours is a large tertiary care referral center, the acuity and severity of pathology referred to our institution may have presented the investigators with a higher-risk population; therefore results may not be generalizable to the overall population of spine surgery patients. Given these factors, the patients' underlying pathology and comorbidities are partially responsible for the higher complication incidence reported.

Conclusions

In this observational prospective series, the impact of instrumented fusion on incidence of perioperative complications was analyzed. The incidence of complications was noted to be significantly elevated in the fusion cohort than the decompression-alone cohort. For many patients, the need for biomechanical stability dictates the need for a fusion procedure. However, there has been an increase in the application of instrumentation to treat common diseases such as degenerative spinal stenosis, sometimes despite the lack of demonstrated benefit over decompression alone.[9,13,15,25] A full understanding of the consequence of spinal fusion in relationship to complication incidence may aid in patient counseling and in the choice of operative intervention.

Disclosure

Dr. Harrop is a consultant for DePuy Spine, receives research support from the North American Clinical Trials Network, and has financial relationships with Neuralstem and Geron. The remaining authors report no other conflicts 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: Campbell, Yadla, Malone, Ratliff. Acquisition of data: Campbell, Yadla, Malone, Ratliff. Analysis and interpretation of data: Campbell, Malone, Ratliff. Drafting the article: Campbell. Critically revising the article: Campbell, Yadla, Harrop, Ratliff. Statistical analysis: Campbell, Maltenfort, Ratliff. Administrative/technical/material support: Campbell, Harrop, Sharan, Ratliff. Study supervision: Harrop, Sharan, Ratliff.

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Manuscript submitted February 6, 2011.
Accepted July 15, 2011.
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Neurosurg Focus 31 (4):E11, 2011

Accuracy of the freehand technique for 3 fixation methods in the C-2 vertebrae

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Object. Intraoperative imaging often does not provide adequate visualization to ensure safe placement of screws. Therefore, the authors investigated the accuracy of a freehand technique for placement of pars, pedicle, and intralaminar screws in C-2.

Methods. Sixteen cadaveric specimens were instrumented freehand by 2 experienced cervical spine surgeons with either a pars or pedicle screw, and bilateral intralaminar screws. The technique was based on anatomical starting points and published screw trajectories. A pedicle finder was used to establish the trajectory, followed by tapping, palpation, and screw placement. After placement of all screws (16 pars screws, 16 pedicle screws, and 32 intralaminar screws), the C-2 segments were disarticulated, radiographed in anteroposterior, lateral, and axial planes, and meticulously inspected by another spine surgeon to determine the nature and presence of any defects.

Results. A total of 64 screws were evaluated in this study. Pars screws exhibited 2 critical defects (1 in the foramen transversarium and 1 in the C2–3 facet) and an insignificant dorsal cortex breech, for an overall accuracy rate of 81.3%. Pedicle screws demonstrated only 1 insignificant violation (inferior facet/medial cortex intrusion of 1 mm) with an accuracy rate of 93.8%, and intralaminar screws demonstrated 3 insignificant violations (2 in the ventral canal, 1 in the caudad lamina breech) for an accuracy rate of 90.6%. Pars screws had significantly more critical violations than intralaminar screws ($p = 0.041$).

Conclusions. Instrumentation of the C-2 vertebrae using the freehand technique for insertion of pedicle and intralaminar screws showed a high success rate with no critical violations. Pars screw insertion was not as reliable, with 2 critical violations from a total of 16 placements. The freehand technique appears to be a safe and reliable method for insertion of C-2 pedicle and intralaminar screws. *(DOI: 10.3171/2011.6.FOCUS1167)*

Key Words • **intralaminar screw** • **pedicle screw** • **pars screw** • **freehand technique** • **cervical spine** • **fixation**

Recently, C-1 and C-2 screws in the pedicle, pars/isthmus, and lamina with various rod and/or plate constructs have become popular because of their decreased risk of injuring the vertebral artery compared with previously described techniques.[2,8,9,11,13,14,18,25] C-2 pedicle and pars screws require thorough preoperative planning with CT because of the potential injury to the vertebral artery at the foramen transversarium (Fig. 1).[6] Pars/isthmus screws are typically reserved for salvage operations in patients in which other techniques are not feasible because the C-2 pars screw provides inferior biomechanical stabilization compared with pedicle and transarticular screws.[20] Intralaminar screws avoid the vertebral artery and provide effective stabilization, but there is an increased risk of a ventral cortical breech with intrusion into the canal.[10,12]

Although these screw-rod constructs are promising in addressing atlantoaxial instability, they are technically demanding and require extensive preoperative planning to ensure accurate placement of the screws. Additionally, there is limited literature on the use of the freehand technique for placement of C-2 pars, pedicle, and intralaminar screws, and intraoperative imaging often does not provide adequate visualization to ensure safe placement of each screw. Therefore, the purpose of this study was to investigate the use of a freehand technique for placement of pars, pedicle, and intralaminar screws in C-2.

Methods

Study Material

Following approval from the Institutional Review Board at Walter Reed Army Medical Center, 16 fresh-frozen human cadaveric spines (from the occiput to C1–T2) were obtained from the State Anatomy Board. All specimens underwent imaging prior to instrumentation

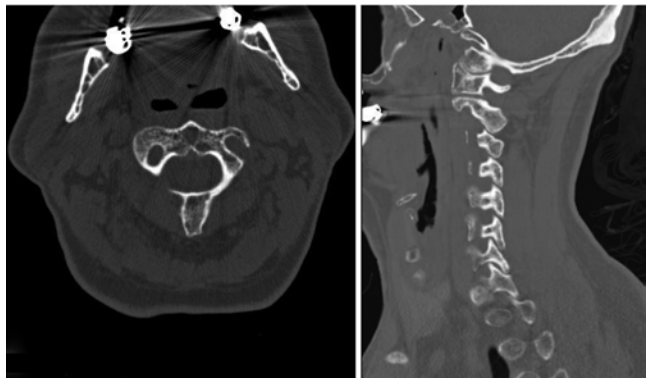


Fig. 1. Preoperative imaging is critical in evaluating the bone anatomy to determine if pedicle or pars screws are an option. Axial CT scans are the best images to evaluate the pedicle **(left)**, whereas sagittal images best demonstrate the pars interarticularis **(right)**.

to rule out any osseous abnormality, with anteroposterior and lateral radiographs serving as guides for screw placement. Specimens were cleaned of soft tissue posteriorly to expose the posterior spinous process and lamina of C-2. Two experienced cervical spine surgeons (K.D.R. and R.C.S.) using pedicle, pars, and intralaminar screws instrumented the 16 cadaveric spines. Half of the 16 specimens received bilateral pedicle screws (16 total), and the remaining specimens received bilateral pars screws (16 total). All specimens received bilateral intralaminar screws (32 total).

Pedicle Screws

For the pedicle screws, a 4.0 × 20–mm polyaxial screw (VertexMax; Medtronic, Inc.) was placed using the Harms technique, with the anatomical starting point in the cranial and medial quadrant of the isthmus of C-2, and a trajectory of 20–30° in a convergent and cephalad direction in reference to the superior and medial surface of the C-2 isthmus (Fig. 2).[11]

Pars Screws

The pars screws were either 4.0 × 16– or 4 × 18–mm polyaxial screws. The starting point for the pars screw placement was 2–3 mm lateral and 2–3 mm above the medial aspect of the C2–3 facet (similar to a C1–2 transarticular screw), with a trajectory directed toward the C1–2 facet (Fig. 2).

Intralaminar Screws

A 4.0 × 20–mm polyaxial screw was placed into the lamina according to the technique described by Wright.[25] The starting point was the junction of the lamina and spinous process with the path directed contralaterally and the trajectory slightly less than the downward slope of the lamina. For all techniques, a pedicle finder was used to determine the path for the intralaminar screw; the pedicle was then tapped and palpated, and the screw was placed. Following placement of all the screws, the C-2 segments were disarticulated and radiographed in anteroposterior, lateral, and axial planes. Another spine surgeon determined the presence and nature of any defects by meticulously inspecting the segments.

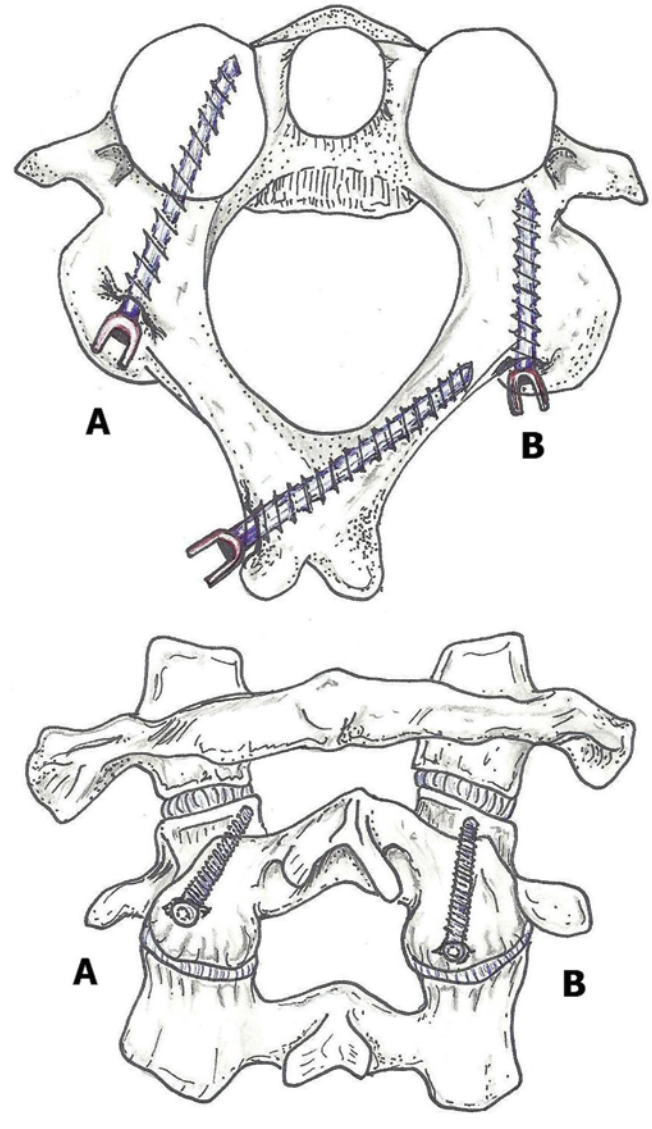


Fig. 2. Pedicle and pars screws differ slightly in their starting points and trajectory. The starting point for a pedicle screw **(A)** is more cephalad than the pars screw, whereas the pars screw **(B)** starts more caudal and aims more cephalad. The medial/lateral starting point is best determined intraoperatively using manual palpation of the medial border of the pedicle/pars using a nerve hook or Penfield 4 dissector.

Statistical Analysis

For statistical analysis, groups were compared using the Pearson chi-square test for categorical data. A probability value < 0.05 was considered statistically significant.

Results

A total of 16 pars, 16 pedicle, and 32 intralaminar screws (for a total of 64) were evaluated in this study. Anteroposterior and lateral radiographs obtained prior to instrumentation did not reveal any osseous abnormalities or anatomical variations. Following instrumentation and disarticulation, no additional anatomical variations in the osseous anatomy of C-2 were observed.

Pars Screws

Pars screws exhibited 2 critical defects: 1 foramen transversarium violation (Fig. 3) and 1 violation of the C2–3 facet. Subsequent radiographic evaluation and inspection following disarticulation of the C-2 vertebrae with the foramen transversarium violation revealed no anatomical abnormalities. The screw placed into the C2–3 facet appeared to have a trajectory not sufficiently cephalad to stay within the pars. In addition, 1 pars screw demonstrated an insignificant dorsal cortex breech. Upon radiographic evaluation, this screw appeared in an appropriate trajectory, but with visual inspection, the screw trajectory should have been less cephalad or a short screw placed. Thus, the freehand technique for pars screws placement demonstrated an accuracy rate of 87.5% (14/16) in avoiding a critical violation and a total accuracy rate of 81.3% (13/16).

Intralaminar Screws

Intralaminar screws demonstrated 3 insignificant violations: 2 ventral canal intrusions (Fig. 4) and 1 caudal lamina breech. The ventral canal violations were considered insignificant because the violation was less than 2 mm, a threshold extrapolated from a well-established level for the medial violation of pedicle screws. The overall accuracy rate of laminar screws was 90.6%, which was not significantly greater than the overall accuracy of pars screw insertion ($p = 0.355$); however, there were no critical violations, which was statistically significant ($p = 0.041$).

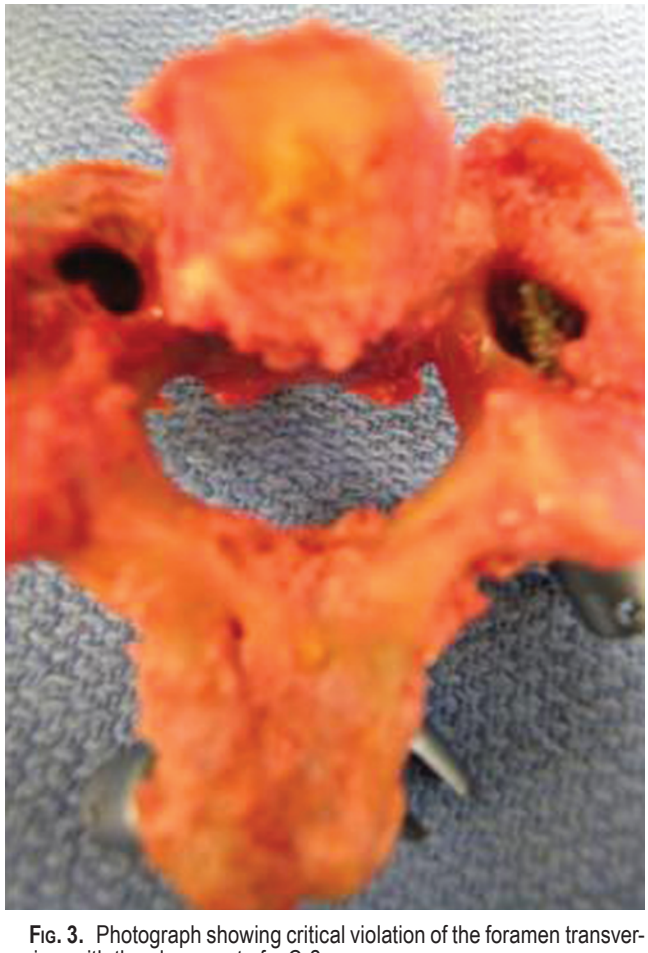


Fig. 3. Photograph showing critical violation of the foramen transversarium with the placement of a C-2 pars screw.



Fig. 4. Photograph showing a less than 2-mm violation of the ventral cortex with a C-2 lamina screw.

Pedicle Screws

Pedicle screws exhibited a single, insignificant, inferior facet medial cortex intrusion of 1 mm, for an accuracy rate of 93.8%. Similar to intralaminar screws, this was not statistically significant compared with pars screws ($p = 0.285$). There were no critical violations compared with 2 violations with the pars screws, but this was not significant ($p = 0.144$), likely due to the small sample size.

Discussion

Although transarticular screws provide higher fusion rates than posterior wiring techniques, the procedure is technically demanding, and the procedure is contraindicated due to screw trajectory endangering the vertebral artery in as many as 20% of patients.[1] Additionally, screw placement in C-2 poses risks to the surrounding neurovascular structures, especially the vertebral artery. Intraoperative fluoroscopy aids the surgeon in evaluating correct screw placement, but it is often inadequate in ensuring safe placement of all screws. Therefore, the goal of this study was to evaluate the use of a freehand technique in placing pars, pedicle, and intralaminar screws in the C-2 vertebra.

Overall the pedicle and intralaminar screws had the highest success rate, with 1 and 3 insignificant violations, respectively. The pars screws were not as reliable and demonstrated 2 critical violations (1 in the foramen transversarium and 1 in the C2–3 facet) and 1 insignificant dorsal cortex breech, for an accuracy rate of 81.3%.

Initially, pedicle screw placement was believed to pose substantially less of a risk to the vertebral artery than transarticular screws, but the literature now suggests that the anatomical risk to the vertebral artery between

the 2 techniques may be similar.[26] Although the trajectory of the pedicle screw should theoretically avoid injuring the vertebral artery, anatomical reports of the presence of a high-riding C-2 transverse foramen in 18% of patients, vertebral artery erosion of the lateral mass and pedicle, and an anomalous vertebral artery increase the risk of injuring the artery.[5,6,13,17,21,24] However, the technique described by Harms and others, utilizing a lateral-to-medial trajectory and oriented in the cephalad direction, has been reported to provide satisfactory stabilization with minimal complications.[11,16] The use of intraoperative fluoroscopy for screw placement was reported to have an overall 2.7% complication rate in a report of 79 patients, with 1 case of injury to the vertebral artery without any neurological complications.[16] The freehand pedicle screw technique had 1 insignificant breech of the inferior facet/medial cortex, which has been reported as one of the more common complications with pedicle screw placement.[16] This complication is likely the result of the medial/cephalad trajectory advocated by Harms and others to avoid injury to the vertebral artery, in addition to the narrow isthmus of C-2.[11,19] Thus, the results of this study suggest that the freehand method is a viable technique for safely and efficiently placing pedicle screws, although further clinical evaluation is warranted.

The use of pars screws in stabilizing the atlantoaxial complex is typically reserved for salvage operations or when the patient's anatomy or pathology excludes other techniques as safe alternatives. Ebraheim et al.,[7] in their anatomical study, defined the par interarticularis as the narrow portion of the axis between the superior and inferior facets. In this study the use of freehand techniques to place pars screw resulted in the most significant complications. Therefore, given the 2 major complications associated with the freehand technique for placement of pars screws and significant variability in C-2 vertebral anatomy, placement of pars screws should be restricted to those patients in whom other techniques have failed. In addition, preoperative and intraoperative imaging should be used to the fullest extent to ensure proper placement of the pars screws.

Intralaminar screws in C-2 provide a unique platform for addressing atlantoaxial instability due to its application to a wide variety of patients and avoiding injury to the vertebral artery.[15,22,23,25] In addition, this technique is able to be performed without fluoroscopy and is less technically demanding than other rigid fixation techniques. Several biomechanical studies suggest that an intralaminar screw is a stable anchor that is equivalent to other rigid fixation techniques.[4,10,12] The lamina of C-2 is the largest cervical lamina and is able to accommodate 20-mm-long screws in 99% of patients, but several cadaveric studies indicate a larger variability in lamina diameter restricting screw diameter.[3,22,25] Wright[25] discussed one potential complication from C-2 intralaminar screw placement as the intrusion of a screw into the spinal canal; furthermore, he advised a trajectory less than the dorsal cortex of the lamina in an effort to avoid a ventral cortex breech. However, breech of the ventral canal intraoperatively is reported in the literature and was reproduced in this study, but no neurological complications have been reported in association with this complication to date.[23,25] The 2 ventral breeches observed in this study could have possibly been avoided by using a smaller diameter screw. The cadaveric study by Wang[22] reported that as many as 47% of C-2 lamina bilaterally are unable to accommodate a 4.0-mm screw at its thinnest diameter. Biomechanical data in the literature support the view that smaller screws are equivalent to pedicle screws in establishing rigid fixation. Thus, the freehand technique used in this study was associated with a breech in the ventral cortex, and although this complication has not been associated with any adverse complications, the use of smaller screws in appropriate patients could possibly reduce this complication.

Weaknesses of this study include its cadaveric design, in which additional intraoperative soft tissue and position could limit adequate screw placement. In addition, imaging was unable to adequately assess the vascular structures in the cadaveric specimens, which could have been useful in preoperative planning. Furthermore, the use of more specimens would have also increased reliability and yielded more accurate results. Nevertheless, the practical applications of this study support the use of freehand techniques in placement of pedicle and laminar screws, which reduces operative time and intraoperative radiation exposure.

Conclusions

Instrumentation of the C-2 vertebrae using the freehand technique for insertion of pedicle and intralaminar screws showed a high success rate with no critical violations. Pars screw insertion was not as reliable with 2 critical violations from a total of 16 screws placed. The freehand technique appears to be a safe and reliable method for insertion of C-2 pedicle and intralaminar screws.

Disclosure

Dr. Riew served as a consultant to Biomet, has direct stock ownership in Vertiflex, Benevenue Medica, Paradigm Spine, PSD, Osprey, Expanding Orthopedics, Spineology, Spinal Kinetics, Amedica, and Nexgen Spine. He has also received royalties from Biomet, Medtronic, and Osprey. Dr. Sasso is a patent holder with Medtronic.

Author contributions to the study and manuscript preparation include the following. Conception and design: Lehman, Helgeson, Sasso, Riew. Acquisition of data: Helgeson, Dmitriev. Analysis and interpretation of data: Lehman, Helgeson, Dmitriev, Sasso, Riew. Drafting the article: Helgeson. Critically revising the article: Lehman, Helgeson, Dmitriev, Kang. Administrative/technical/material support: Kang, Tannoury. Study supervision: Lehman, Sasso, Riew. Final revision and online submission: Kang. Illustrations: Tannoury.

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Manuscript submitted February 21, 2011.
Accepted June 8, 2011.

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Neurosurg Focus 31 (4):E12, 2011

Anterior corpectomy versus posterior laminoplasty: is the risk of postoperative C-5 palsy different?

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Object. Both anterior cervical corpectomy and fusion (ACCF) and laminoplasty are effective treatments for selected cases of cervical stenosis. Postoperative C-5 palsies may occur with either anterior or posterior decompressive procedures; however, a direct comparison of C-5 palsy rates between the 2 approaches is not present in the literature. The authors sought to compare the C-5 palsy rate of ACCF versus laminoplasty.

Methods. The authors conducted a retrospective review of 31 ACCF (at C-4 or C-5) and 31 instrumented laminoplasty cases performed to treat cervical stenosis. The demographics of the groups were similar except for age (ACCF group mean age 53 years vs laminoplasty group mean age 62 years, $p = 0.002$). The mean number of levels treated was greater in the laminoplasty cohort (3.87 levels) than in the ACCF cohort (2.74 levels, $p < 0.001$). The mean preoperative Nurick grade of the laminoplasty cohort (2.61) was higher than the mean preoperative Nurick grade of the ACCF cohort (1.10, $p < 0.001$).

Results. The overall clinical follow-up rate was 100%. The mean overall clinical follow-up was 15 months. There were no significant differences in the estimated blood loss or length of stay between the 2 groups ($p > 0.05$). There was no statistical difference between the complication or reoperation rates between the 2 groups ($p = 0.184$ and $p = 0.238$). There were 2 C-5 nerve root pareses in each group. Three of the 4 patients recovered full deltoid function, and the fourth patient recovered nearly full deltoid function at final follow-up. There was no statistical difference in the rate of deltoid paresis (6.5%) between the 2 groups ($p = 1$).

Conclusions. Both ACCF and laminoplasty are effective treatments for patients with cervical stenosis. The authors found no difference in the rate of deltoid paresis between ACCF and laminoplasty to treat cervical stenosis. *(DOI: 10.3171/2011.8.FOCUS11156)*

Key Words • **cervical laminoplasty** • **anterior cervical corpectomy and fusion** • **C-5 palsy** • **deltoid palsy**

Temporary C-5 paresis or palsy involving the deltoid and/or biceps brachii muscles may occur after cervical spinal surgery. The actual etiology, risk factors, and prognostic factors for C-5 palsy remain uncertain. The incidence has been frequently reported in series of cervical decompression surgery to range from 0% to 17%.[34,36,37]

Both ACCF and laminoplasty are accepted procedures to treat cervical stenosis.[10,18–21] In the literature, there are currently more reports of C-5 palsy with posterior cervical decompression surgery than with anterior cervical surgery.[3,6–9,12–15,17,22,29,30,35,36] However, anterior cervical decompressive procedures such as ACDF or ACCF have also been reported to be associated with postoperative C-5 palsy.[5,27,34,36,37] Despite the knowledge that a C-5 palsy is a risk of either procedure, the relative risk of C-5 palsy with anterior versus posterior surgery remains uncertain.

We hypothesized that there would be no difference in the postoperative C-5 palsy rate between ACCF and instrumented open-door laminoplasty.

Methods

Patient Demographics

We reviewed the records of all patients with cervical stenosis involving the C4–5 level who were treated with ACCF or laminoplasty between 2006 and 2011. All operations were performed by a single neurosurgeon (P.V.M.). Patients with traumatic fractures of the cervical spine, prisoners, and patients with tandem neurological conditions such as polio were excluded. Between 2006

Abbreviations used in this paper: ACCF = anterior cervical corpectomy and fusion; ACDF = anterior cervical discectomy and fusion; EBL = estimated blood loss; LOS = length of stay; MRC = Medical Research Council; OPLL = ossification of the posterior longitudinal ligament; PEEK = polyetheretherketone.

and 2011, 62 consecutive patients who met the inclusion and exclusion criteria were selected. Of this total group, 31 had undergone ACCF and 31 had undergone laminoplasty (Table 1).

Anterior Cervical Corpectomy and Fusion Group. All 31 patients undergoing ACCF had 2 or more levels of stenosis (involving C4–5 due to OPLL) (in 9) or degenerative spondylosis (in 22). Eight patients had a C-4 corpectomy, 22 patients had a C-5 corpectomy, and 1 patient had C-4 and C-5 corpectomies. Of the 8 C-4 corpectomy patients, 1 also had a nonadjacent C-6 corpectomy and 3 had an additional adjacent ACDF. Of the 22 patients who had C-5 corpectomies, 4 patients also had concomitant C-6 corpectomies and 8 had an additional adjacent ACDF (Fig. 1).

There were 18 male patients and 13 female patients in this group, with a mean age of 53 years. The mean number of levels treated (disc spaces) was 2.7. The mean preoperative and postoperative Nurick grades were 1.10 and 0.74, respectively.

Laminoplasty Group. During the same period, the senior author (P.V.M.) performed 31 laminoplasty operations in patients with cervical stenosis due to either OPLL or degenerative spondylosis that included decompression of the C4–5 spinal canal level. All patients had 3 or more levels of stenosis, and none had cervical kyphosis. Patients who required extension of decompression to C-2 or T-1 with fusion were not included in this cohort.

The mean age in the laminoplasty group was 62 years. There were 24 male patients and 7 female patients. A mean of 3.87 levels were treated. Of the 31 patients who underwent laminoplasty, 15 had degenerative spondylosis and 16 had segmental OPLL.

There was no statistical difference regarding sex between the laminoplasty and ACCF groups ($p > 0.05$), but there was a statistically significant difference between the ages of the patients in the laminoplasty cohort (mean age 62 years) and the ACCF cohort (mean age 53 years) ($p = 0.002$). The mean preoperative Nurick grade in the laminoplasty cohort (2.61) was significantly higher ($p < 0.001$) than the preoperative Nurick grade (1.10) in the ACCF cohort (Table 2).

Patient Assessment

Perioperative Data. Perioperative data were collected for all patients and included EBL, number of levels treated, LOS, complications, and reoperations. Intraoperative monitoring with somatosensory and motor evoked potentials and electromyography was performed during all index surgeries. The incidence of postoperative C-5 paresis was also documented.

Clinical Outcome. Deltoid paresis/palsy was evaluated using the MRC scoring system.[24] Overall functional outcomes were evaluated by comparing preoperative and postoperative Nurick grades.

Statistical Analysis

Continuous data were analyzed using standard parametric and nonparametric tests. Categorical data were evaluated using contingency table analysis. A p value < 0.05 was considered statistically significant.

Surgical Technique

Anterior Cervical Corpectomy and Fusion Group. All patients underwent a minimum of a C-4 and/or C-5 ACCF with the use of a PEEK cage, local autograft, and anterior plate fixation. Additional stenotic levels were decompressed with either ACDF or another level of ACCF during the same operation.

The corpectomy was performed using a drill, and the adjacent discs were removed using curettes and pituitary rongeurs. The bone from the corpectomy was used as local autograft. A matchstick drill bit was used to drill down to the posterior longitudinal ligament. The posterior longitudinal ligament was elevated using a blunt tip nerve hook, which was then incised and removed to thoroughly decompress the dura. In cases of OPLL, a central region of ossification was occasionally left in place if a plane could not be easily developed between the OPLL and dura. The superior and inferior posterior lipping endplate osteophytes were then drilled using the matchstick drill bit and undercut with a Kerrison rongeur. Bilateral foraminotomies were performed at each level to ensure adequate foraminal decompression. The corpectomy cage size was then determined using a trial, and the appropriate PEEK cage filled with local autograft was placed. Anterior plate fixation was performed using a nontranslational plate (Atlantis, Medtronic) with the use of variable screws on the superior fixation points and fixed screws on the inferior fixation point (Fig. 2).

TABLE 1: Inclusion and exclusion criteria for the ACCF and laminoplasty groups*

Criteria	ACCF	Laminoplasty
inclusion	degenerative cervical spinal canal stenosis or OPLL w/ ant compression involving the C-4 &/or C-5 levels	multi-level cervical spinal canal stenosis due to degenerative spondylosis or OPLL involving the C-4 & C-5 levels
exclusion	prior ant cervical op involving the C4–5 level	prior posterior cervical op involving the C4–5 level
	traumatic fractures of the cervical spine	traumatic fractures of the cervical spine
	extension of compression levels to C-2 or T-1	extension of compression levels to C-2 or T-1
	other neurological diseases (e.g., polio, MS, & CMT disease)	other neurological diseases (e.g., polio, MS, & CMT disease)
	cervical kyphosis	cervical kyphosis
	posterior cervical fusion	posterior cervical fusion

* ant = anterior; CMT = Charcot-Marie-Tooth; MS = multiple sclerosis.

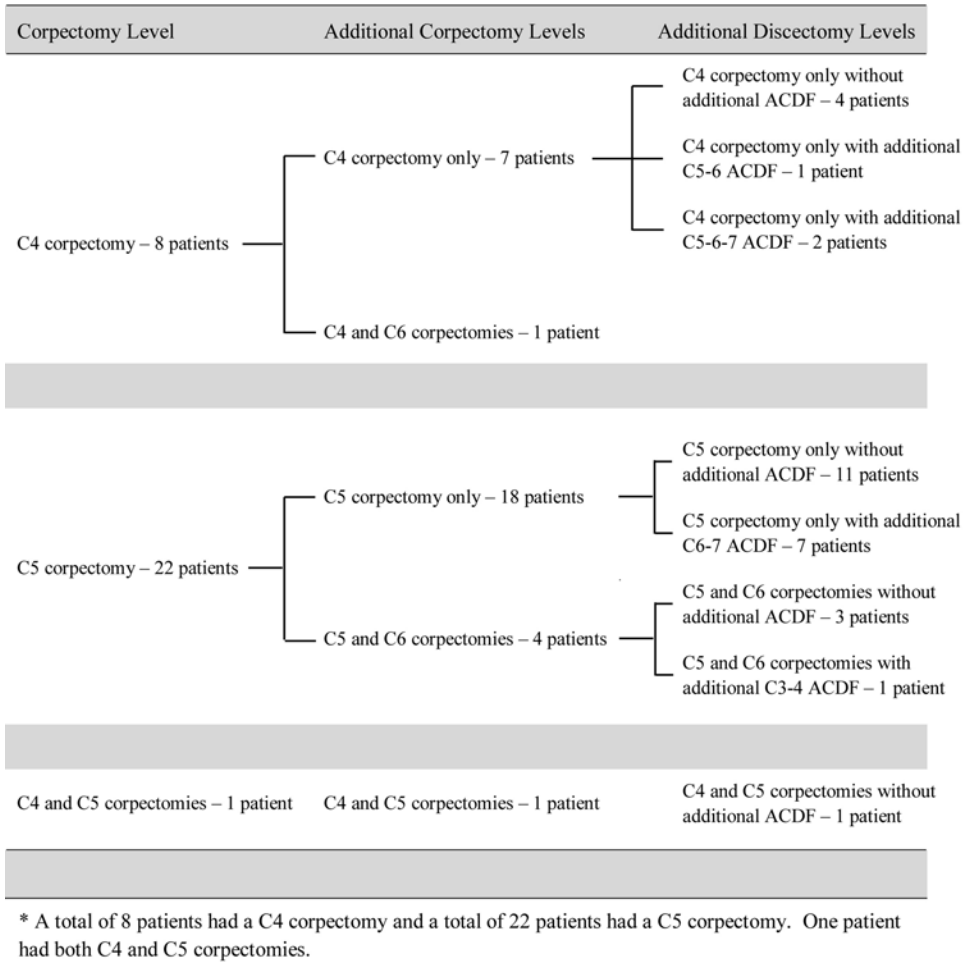


Fig. 1. Levels of anterior cervical corpectomy and accompanying ACDF levels.

Laminoplasty Group. There are several commonly used techniques for laminoplasty, including single- and double-hinged door with or without instrumentation.[1,4,25,28,31] All patients underwent open-door laminoplasty with titanium miniplates (Centerpiece, Medtronic) without bone graft. A 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 same drill bit, and this side was used as a hinge to open the laminoplasty. The hinged, open-door laminoplasty was secured using 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. An additional unilateral posterior foraminotomy on the plated side was carried out only if cervical radiculopathy was also present. Patients underwent laminoplasty from C-3 to C-5, C-6, or C-7 depending on the extent of the stenosis (Fig. 3).

Results

The clinical follow-up rate of all patients was 100%. The mean clinical follow-up period was 15 months (12 months for ACCF patients and 18 months for laminoplasty patients). Of the total 62 patients, 4 developed deltoid paresis. Three of the 4 patients recovered full deltoid function, and the fourth patient recovered nearly full deltoid function at final follow-up. Three of the 4 patients developed deltoid paresis immediately postoperatively, and the remaining patient developed deltoid paresis on the next day following a reoperation for a collapsed laminoplasty segment. Three of the 4 patients had a severe deltoid paresis (MRC motor Grade 1–2/5) and the remaining patient had a mild deltoid paresis (MRC motor Grade 3/5). In the ACCF group, the deltoid paresis rate was 6.5% (2 deltoid pareses). One of these cases had full recovery of deltoid function, but the other patient had only a partial recovery (MRC motor Grade 4/5) of deltoid function. The deltoid paresis rate for the laminoplasty group was also 6.5% (2 deltoid pareses). These resolved completely by 18 months postoperatively (Table 3).

Perioperative Data

The mean number of levels treated in the ACCF group was 2.7. The mean EBL was 278 ml, and the mean hospital stay was 3.8 days. Six patients developed postoperative dysphagia, and 1 patient required temporary nasogastric tube placement. All dysphagia cases resolved completely. There were no infections or reoperations in the ACCF group.

TABLE 2: Comparison of demographics, clinical outcomes, and complications of ACCF with instrumented laminoplasty

Parameter	ACCF	Laminoplasty	p Value
no. of patients	31	31	
mean follow-up (mos)	12	18	0.021*
mean age (yrs)	53	62	0.002*
sex			0.174
male	18	24	
female	13	7	
mean LOS (days)	3.8	3.8	0.116
mean EBL (ml)	278	171	0.195
mean no. of levels	2.74	3.87	<0.001*
mean preop Nurick grade	1.10	2.61	<0.001*
mean postop Nurick grade	0.74	1.19	0.065
no. of C-5 palsies	2	2	1.000
no. of reops	0	3	0.238

* Statistically significant.

Intraoperative monitoring with somatosensory and motor evoked potentials and electromyography was used during all index surgeries. We found that only 1 of the 4 patients with deltoid palsy had an intraoperative decrease in motor evoked potentials, but this occurred during the corpectomy and not during the nerve root decompression portion of the procedure. The remaining 3 patients did not show any change on intraoperative monitoring.

The mean number of levels treated for the laminoplasty group was 3.87. The mean EBL was 171 ml, and the mean hospital stay was 3.8 days. The reoperation rate for the laminoplasty group was 9.7% (2 wound infections and 1 collapsed laminoplasty segment that caused restenosis). The patients with wound infections were treated with a wound debridement, and all hardware was left in place. These patients were given 6 weeks of intravenous antibiotics followed by 12 months of oral antibiotics. In the patient with the collapsed laminoplasty segment, the hinged side of C-4 had fractured into the spinal canal. This was corrected by performing a laminectomy of C-4. This patient then developed a temporary C-5 nerve root paresis 1 day after the reoperation (1 of the 2 patients with a deltoid paresis in the laminoplasty group). There were no perioperative deaths, but during the follow-up period, 3 patients (all in the laminoplasty group) died of causes not related to the surgery. As previously noted, the laminoplasty group was significantly older and had more severe myelopathy than did the ACCF group.

Clinical Measurement

There were no significant differences in the EBL and the LOS between the 2 groups ($p > 0.05$), and the overall complication rate between the 2 groups was not statistically different. The rate of reoperations (0% for ACCF and 9.7% for laminoplasty, $p = 0.238$) was not significantly different between the groups. There was no difference in the rate of deltoid paresis ($p = 1$) between the 2 groups. There was a statistically significant improvement in the Nurick grades for the laminoplasty group ($p < 0.001$). The Nurick grades for the ACCF group also improved, but this trend did not reach statistical significance ($p = 0.144$).

Discussion

The etiology of postoperative C-5 paresis is not known. Potential causes include local nerve root trauma during surgery, nerve root traction caused by shifting of the cord following decompression surgery (that is, the "tethering phenomenon"), or spinal cord ischemia due to decreased blood supply from radicular arteries.[2,11,26] None of the above hypotheses has been proven, and evidence to refute each can be found in the literature.

The fact that the C-5 root appears highly susceptible to injury may be related to several anatomical features of the cervical spine. First, the superior articular process of C-5 protrudes in a more anterior direction than at other levels, and the rootlets of C-5 are shorter than those of other segments. Furthermore, the C-5 segment is usually the point at which the extent of posterior shift of the cord is greatest. Using cadavers, Tsuzuki et al.[32,33] demonstrated that impingement of the nerve root occurs inside the uncovertebral joint with backward shifting of the spinal cord after laminoplasty.

In a literature review of C-5 palsy after decompres-

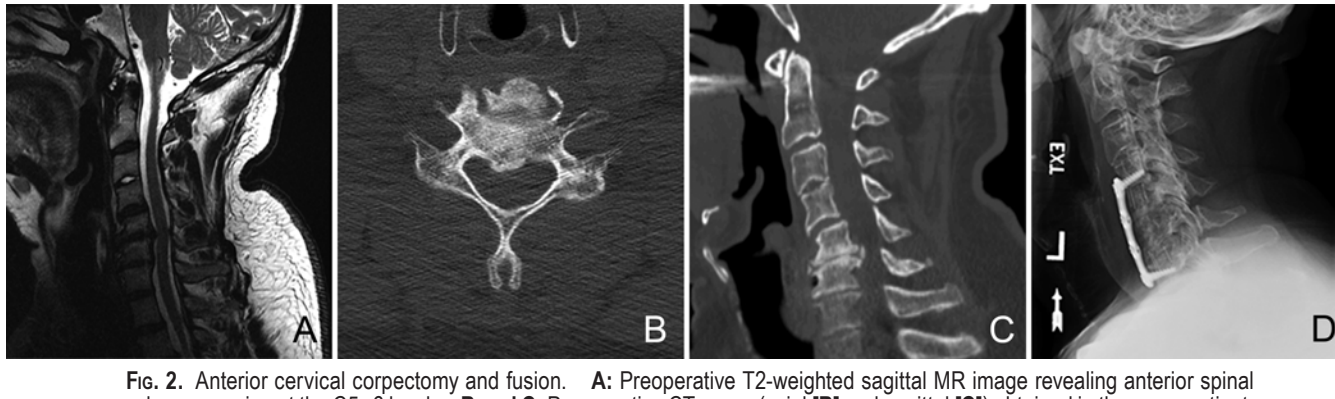


Fig. 2. Anterior cervical corpectomy and fusion. **A:** Preoperative T2-weighted sagittal MR image revealing anterior spinal canal compression at the C5–6 level. **B and C:** Preoperative CT scans (axial **[B]** and sagittal **[C]**) obtained in the same patient, revealing ossification behind the C-5 vertebral body. **D:** Postoperative lateral radiograph following a C-5 and C-6 corpectomy with a PEEK cage filled with local autograft and anterior cervical plate reconstruction.

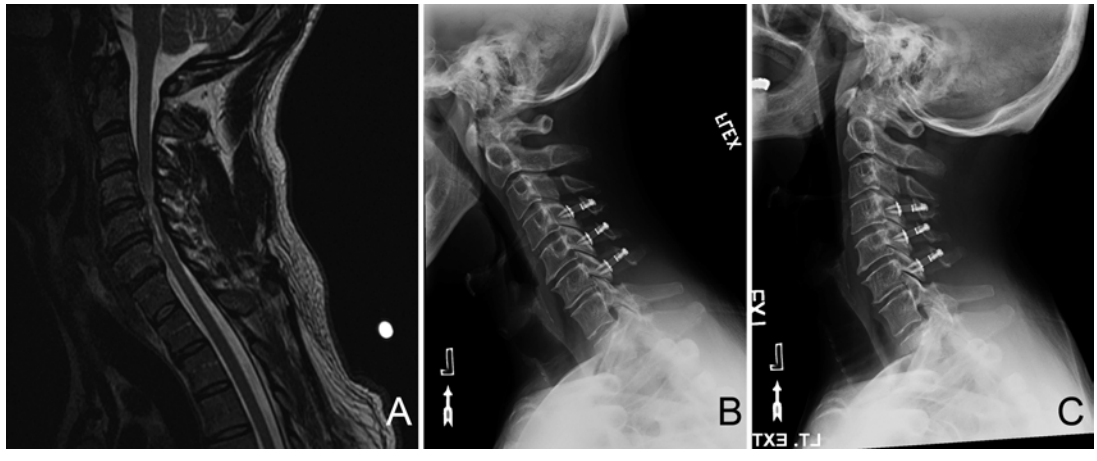


Fig. 3. Laminoplasty. **A:** Preoperative T2-weighted sagittal MR image revealing cervical canal stenosis from the C-4 to C-6 levels due to degenerative spondylosis. Significant cord signal change is demonstrated. **B and C:** Postoperative dynamic flexion **(B)** and extension **(C)** radiographs of the cervical spine with laminoplasty miniplates at C4–6.

sion surgery for cervical myelopathy spanning 16 years, Sakaura et al.[26] reported that 92% of C-5 palsies occur unilaterally, and the remaining 8% affect muscles bilaterally. The vast majority of C-5 palsies occur within a week after surgery. Paresis of C-6, C-7, or C-8 in isolation or combination has been reported with a much lower incidence, although some of these patients may actually have had a brachial plexitis rather than a nerve root palsy.[2]

A C-5 palsy may occur on a spectrum from immediately postoperatively up to several weeks after the surgery. Komagata et al.[16] reported a series of 305 patients undergoing laminoplasty, of whom 13 developed postoperative C-5 palsy; in 4 of these 13 patients, the onset of motor palsy occurred on the day of the surgery. In another recent paper, Nassr et al.[23] included patients undergoing multilevel cervical corpectomy, corpectomy with posterior fusion, posterior laminectomy and fusion, and laminoplasty. The overall incidence of C-5 nerve palsy was 42 of 630 cases, and, as the authors stated, "the time of initial onset of the C-5 palsy symptoms ranged from immediately postoperatively to 2 months postoperatively."

Sakaura et al.[26] reported that the overall rates of differences in recovery for severe (grade of muscle power of 1–2 of 5 on manual muscle testing) and mild (grade of muscle power 3–4/5) cases of deltoid paresis were not statistically significant, and patients with C-5 palsy generally experienced neurological and functional recovery.

TABLE 3: Postoperative MRC grades of deltoid palsy and their time to complete improvement

Group	No. of Patients w/ Deltoid Palsy	Postop Grade of Deltoid Palsy	
		Immediately Postop	At Follow-Up
ACCF	2	1 (3/5); 1 (2/5)	5/5 at 5 mos; 4/5 at 9 mos
Laminoplasty	2	1 (2/5); 1 (2/5)	5/5 at 12 mos; 5/5 at 18 mos*

* This patient recovered after the second operation on postlaminoplasty Day 2 for a collapsed laminoplasty segment.

However, the latency between the onset of the C-5 paresis and recovery to a useful level (< 3, 3–6, and > 6 months) was significantly longer for the severe cases than for the mild cases.

We defined C-5 palsy strictly as motor paresis of the deltoid muscle and did not include sensory deficits in the C-5 distribution. In our study, we had 2 cases of deltoid paresis in both of the ACCF and the laminoplasty groups. All of the 4 cases were unilateral. Three of the 4 cases had immediate postoperative deltoid paresis, and the other patient developed a deltoid paresis 1 day after he underwent revision surgery to repair a collapsed laminoplasty segment.

In our series, we had 1 case of mild (MRC motor Grade 3–4/5) and 3 cases of severe (MRC motor Grade 1–2/5) deltoid pareses. At final follow-up, 3 of the 4 cases of deltoid paresis recovered fully, and the fourth patient (who had severe MRC motor Grade 1/5 deltoid paresis after an ACCF) recovered strength to an MRC motor grade of 4/5.

Overall, we found no significant differences in the rates of deltoid paresis between patients undergoing ACCF and those undergoing laminoplasty to treat cervical stenosis.

Conclusions

We found that ACCF and laminoplasty procedures lead to neurological improvements in myelopathic patients. The rate of C-5 paresis appears to be similar in patients with cervical stenosis undergoing decompression surgery with either ACCF or laminoplasty involving the C-5 level, although time to improvement in the laminoplasty group was longer than in the ACCF group. Patients with postoperative C-5 paresis generally have a good prognosis for functional recovery, but the cases of severe deltoid paresis (grade of muscle power 1–2/5) require a longer time to recover than do the mild cases.

Disclosure

Dr. Mummaneni is a past consultant for DePuy Spine and Medtronic. He receives other financial support (royalties) from DePuy Spine and Quality Medical Publishers.

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

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Manuscript submitted June 16, 2011.
Accepted August 3, 2011.

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Neurosurg Focus 31 (4):E13, 2011

Complications associated with the treatment for spinal ependymomas

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Spinal cord ependymomas are rare neoplasms, comprising approximately 5% of all CNS tumors and 15% of all spinal cord tumors. Although surgery was once reserved for diagnosis alone, the evolution of surgical practices has elevated resection to the treatment of choice for these lesions. While technological advances continue to improve the capacity for gross-total resections and thus decrease the risk of recurrence, ependymoma spinal surgery still contains a variety of potential complications. The presence of neurological deficits and deterioration are not uncommonly associated with spinal cord ependymoma surgery, including sensory loss, dorsal column dysfunction, dysesthetic syndrome, and bowel and bladder dysfunction, particularly in the immediate postoperative period. Surgical treatment may also lead to wound complications and CSF leaks, with increased risk when radiotherapy has been involved. Radiation therapy may also predispose patients to radiation myelopathy and ultimately result in neurological damage. Additionally, resections of spinal ependymomas have been associated with postoperative spinal instability and deformities, particularly in the pediatric population. Despite the advances in microsurgical techniques and intraoperative cord monitoring modalities, there remain a number of serious complications related to the treatment of spinal ependymoma tumors. Identification and acknowledgment of these potential problems may assist in their prevention, early detection, and increased quality of life for patients afflicted with this disease. *(DOI: 10.3171/2011.7.FOCUS11158)*

Key Words • **complication** • **ependymoma** • **spine** • **surgery** • **treatment**

Spinal cord ependymomas are rare neoplasms and present around a mean age of 40 years.[54] They constitute 3% to 6% of all CNS tumors and 15% of all spinal cord tumors.[17,45,126] These lesions are predominantly slow-growing, benign tumors that tend to compress adjacent structures rather than infiltrate cord parenchyma, resulting in associated symptoms.[56,82,114] In order of decreasing frequency, presentation may include neck or back pain, sensory deficits, motor weakness, and bowel and bladder dysfunction.[54]

The WHO classified ependymomas into 4 distinct subtypes: subependymomas, myxopapillary ependymomas, classic ependymomas, and anaplastic ependymomas.[106,108] Spinal ependymomas may affect any age group, but they are typically found in adults and comprise the myxopapillary or classic subtypes.[45,59,82,89,114] Myxopapillary ependymomas are generally encapsulated and reside primarily in the conus medullaris, but may extend to the cauda equina.[106,108,110] Classic ependymomas generally form in the cervical spine, but occasionally develop in the thoracic region (Fig. 1).[106]

Abbreviations used in this paper: CSI = craniospinal irradiation; EMG = electromyelography; HT = helical TomoTherapy; MEP = motor evoked potential; PFS = progression-free survival; SSEP = somatosensory evoked potential.

While the prognosis for spinal ependymomas is generally very good, there are a number of potential complications associated with their treatment that necessitate a greater awareness. As such, identification and prevention of these key issues may allow for improved outcomes in this patient population.

Resections and Progression-Free Survival

Although surgery was once reserved for diagnosis alone, the evolution of surgical practices has elevated resection to the treatment of choice for these spinal tumors.[24,26,35,56,82] Advances in neuroimaging, intraoperative ultrasonography, electrophysiological cord monitoring, and microsurgical techniques have afforded gross-total resections of intramedullary ependymomas that have historically resulted in unacceptable operative morbidity and mortality.[49,54,82,134] Such advances have cultivated an atmosphere of acceptance for gross-total resection as the treatment goal for intramedullary ependymomas.[14,15,20,23,24,26,33,40,55,56,60,63,82,109,114] This objective is particularly important, as numerous studies have cited the degree of resection as the most significant predictor of PFS,[20,48,127] with total resection being potentially curative.[16,90,108,115,122,139]

It has been noted that at the time of surgery, most spinal ependymomas are contained within well-defined mar-

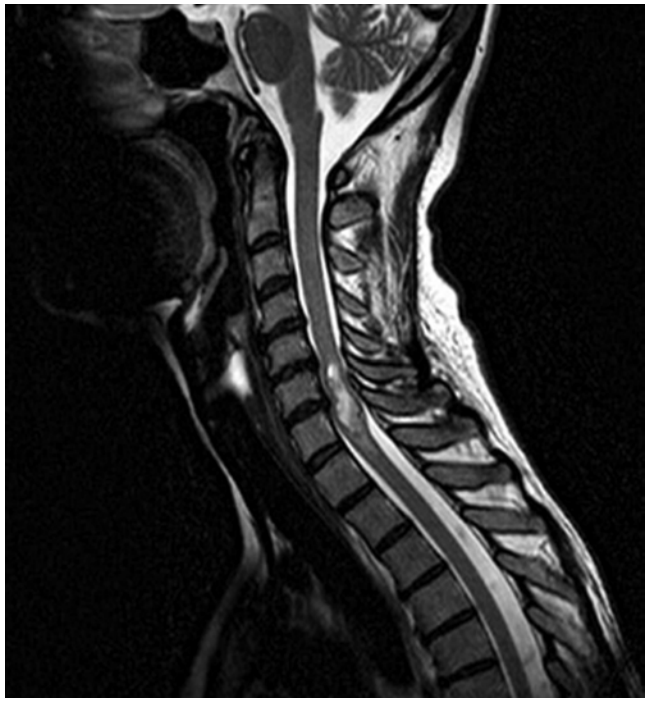


Fig. 1. Sagittal T2-weighted MR image demonstrating a cervical intramedullary ependymoma. Reprinted with permission from Kelleher MO, et al: **J Neurosurg Spine 8:**215–221, 2008.

gins, allowing natural dissection planes to facilitate en bloc resections without disruption of delicate spinal cord parenchyma. However, large tumors are often devoid of such encapsulation, permitting tumor extension to become entangled within the nerve roots and along arachnoid membranes. Such cases may necessitate abandonment of total resections to preserve neurological function and have been associated with a higher rate of recurrence.[13,108] Subsequent internal debulking or intralesional resection may then ensue to release cord tension.[54] However, while CSF dissemination of spinal cord ependymomas is relatively rare, piecemeal removal of tissue during subtotal resections may promote CSF tumor spread.[90,100] Furthermore, subtotal resections may require future reoperation with increased difficulty, as gliosis obscures natural cleavage planes and cord plasticity becomes reduced.[82]

Given the relatively low prevalence of spinal ependymomas, many studies have analyzed data collected over several decades in which surgical and imaging techniques were changing. As such, the rates for total resection and PFS have varied among studies depending on the era in which the data were collected. Abdel-Wahab and colleagues[2] reported a PFS rate of 74%, 60%, and 35% at 5, 10, and 15 years, respectively, in 126 patients undergoing operations dating back as early as 1953. Gomez and colleagues[48] reported a PFS rate of 75%, 50%, and 46% at 5, 10, and 15 years, respectively. Their patients underwent surgery as early as 1955, with an overall recurrence rate of 57% in 37 patients. Recurrence rates by ependymoma subtype have ranged from 25% to 32% for myxopapillary tumors and from 4% to 43% for classic/anaplastic ependymomas.[8,13,46] However, Boström and colleagues[13] reported results for 57 patients undergoing surgery for spinal ependymomas between 1987 and 2007. Their PFS rates were relatively higher than previously reported at 89% and 84% for 5 and 10 years, respectively. Their overall recurrence rate was 9% for all tumors (19% for myxopapillary ependymomas and 5% for classic/anaplastic ependymomas), with 4 of 5 recurrences receiving incomplete resections at initial operation. Furthermore, their rate of complete resection was 84%, compared with those of Abdel-Wahab et al.[2] (50%) and Gomez et al.[48] (55%). Similarly, Yang and colleagues[134] reported a recent study of 85 cases in which almost 93% of spinal ependymomas were amendable to total resection.

While technological advances continue to improve the capacity for gross-total resections and thus decrease the risk of recurrence, ependymoma spinal surgery still contains a variety of potential complications.

Neurological Complications

The presence of neurological deficits and deterioration are not uncommon complications associated with spinal cord ependymoma surgery. Such complications may be particularly incapacitating and slow the patient's progress toward rehabilitation.[135] As preoperative functional status has been assessed as a strong predictor of postoperative functional outcome, it is commonly agreed that early diagnosis and intervention are critical to optimizing neurological status. Thus, treatment should not be postponed until symptomatic functional decline, as severe or long-standing preoperative deficits rarely improve regardless of optimal surgical outcome.[15,26,93,114]

While few studies have assessed postoperative neurological function in patients with spinal cord ependymomas, the majority of patients are said to be prone to increased neurological deficits immediately following resection. Surprisingly, those with minimal preoperative impairments may develop particularly pronounced symptoms. However, patients with minor preoperative complaints have experienced a greater resolution in these deficits than those having more severe preoperative functional symptoms. Such complications are believed to result from a disruption of adjacent microvasculature and edema caused by surgical manipulation of surrounding tissue.[35,56,82] Additionally, tumors originating in the thoracic spine also incur a worse functional prognosis, perhaps due to poor microcirculation[91] and a relatively narrow spinal canal within this region.

The McCormick classification scheme is a grading system to characterize the extent of sensorimotor deficit.[82] In a series of 57 patients, 86% had stable or improved McCormick grades in the immediate postoperative period, whereas 7% experienced a permanent decrease in neurological function.[13] Reports in the literature have similar findings, with 42%–94% of patients achieving improvement of neurological deficits, while neurological decline occurred in 6%–29%.[14,19,24,26,54–56,72,88,93,109] While these defects may not return to their preoperative status, they tend to resolve within 3 months. However, improvement in neurological complications may be appreciable as early as 4 weeks postoperatively and take up to a year to resolve, if ever.[56,71,114]

Sakai and colleagues[108] reported outcomes for 20 patients with myxopapillary spinal ependymomas. Postoperative neurological deterioration was detected in 5 (71%) of 7 patients with unencapsulated ependymomas, while no such complications were observed in 13 patients with encapsulated tumors. Two of those with neurological deficits underwent piecemeal gross-total resection, while the other 3 underwent subtotal resections. As such, it has been suggested that tumor encapsulation may serve as a potential indicator for extent of resection and subsequent postoperative neurological function.

The dictum for resection of spinal cord tumors is to preserve eloquent tissue. In cases in which the ependymoma emerges close to the dorsal surface, a midline myelotomy is advocated as a natural plane of dissection to avoid injury of axonal tracts.[77] Recognition of the accurate midline prior to myelotomy is essential to minimizing neurological defects. The midline in a normal cord is identified by the dorsal median sulcus between the elevated posterior columns (Fig. 2). The entry point of the dorsal median sulcal vein into the midline raphe, as well as the midway point between the opposing root entry zones, may be useful when approximating the medullary midline.[135] While some institutions also rely on identification of posterior spinal arteries in the healthy spinal cord proximally and distally to the tumor to estimate their myelotomy incision site, others use ultrasonography and dorsal cord mapping to localize surgical landmarks.[70,72]

As dorsal column manipulation is an inherent component of spinal cord ependymoma resection, one of the most serious neurological complications is dorsal column dysfunction.[79] The dorsal columns of the spinal cord conduct sensory information associated with proprioception, deep touch, pressure, 2-point discrimination, and vibration.[82] Occasionally, resection may become complicated by cord edema, arachnoid fibrosis, or capillary neovascularization, resulting in cord rotation, asymmetrical enlargement, and obscured delineation of the medullary midline.[135] This can result in an unintentional myelotomy through the dorsal column and subsequent sensory defects, including proprioception loss with secondary gait instability.[28,35,52,56,79,93,114] As the thermal energy emitted

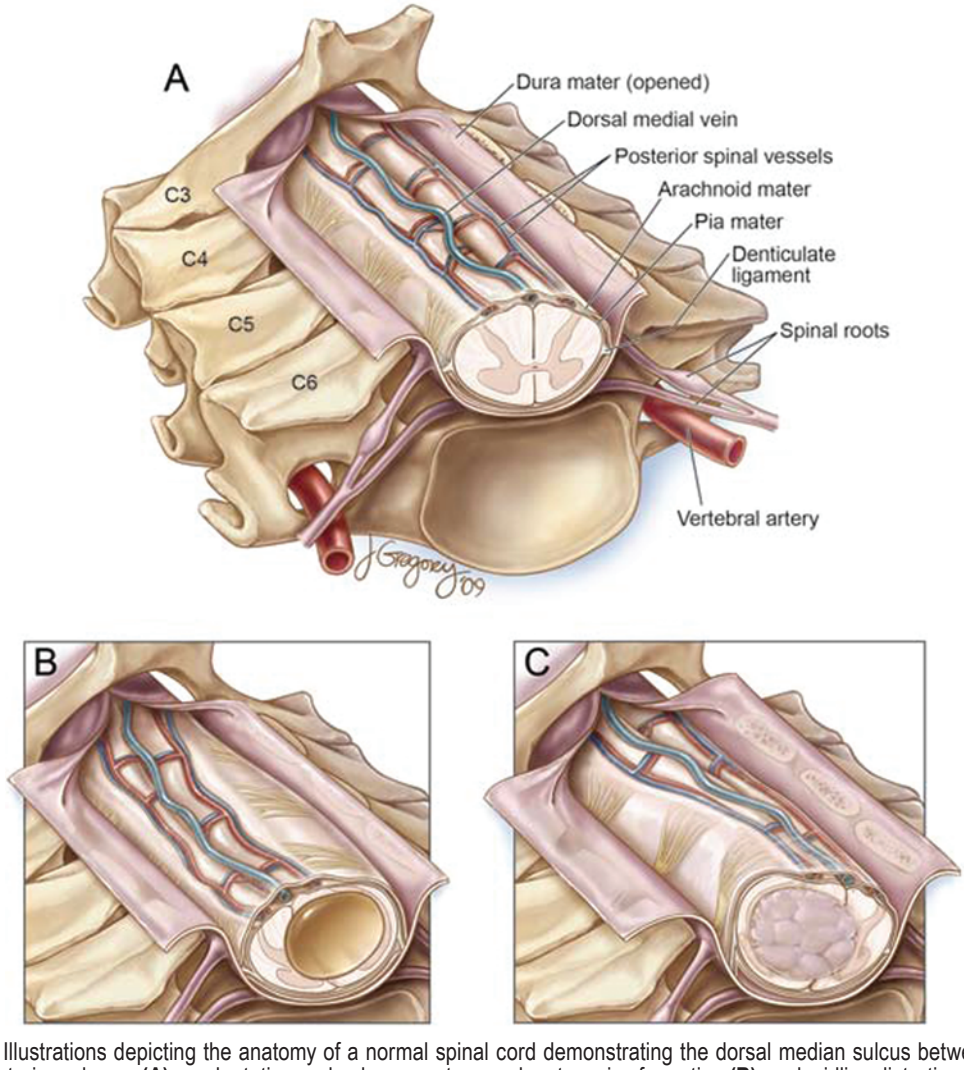


Fig. 2. Illustrations depicting the anatomy of a normal spinal cord demonstrating the dorsal median sulcus between the elevated posterior columns **(A)**, cord rotation and enlargement secondary to syrinx formation **(B)**, and midline distortion secondary to an intramedullary tumor **(C)**. Reprinted with permission from Yanni DS et al: **J Neurosurg Spine 12:**623–628, 2010.

from bipolar electrocautery may cause damage to adjacent spinal tracts, the utilization of sharp dissection in the plane of spinal fibers is the preferred method around these vital areas during tumor resection. Furthermore, debulking the center of the tumor early may aid in establishing the tumor/spinal cord plane prior to dorsal column retraction.[135] Additionally, one author noted that pial retraction stitches may increase the tension on the dorsal columns, and thus should be avoided if possible to reduce the potential damage to these sensitive structures.[70]

Halvorsen and colleagues[52] reported that 28% of 85 patients experienced deterioration of neurological function in the period immediately following surgery, two-thirds of which were due to midline myelotomy. Within this study, 75% of morbidity comprised dorsal column dysfunction. Similarly, Kucia and colleagues[70] presented data in 67 patients with intramedullary ependymomas who underwent resection utilizing modern surgical approaches. Although 26 of their patients developed postoperative dorsal column deficiencies, 23 of these were McCormick Grade I or II at final follow-up.

Another potential neurological complication is dysesthetic syndrome. This phenomenon is a frequent occurrence in the early postoperative period and is found to vary substantially in severity. While some patients report occasional mild sensations of numbness and "pins and needles," others are tormented by persistent causalgia-like dysesthesias described as "itching," "crawling," or "burning." It has been suggested that damage to the dorsal columns or to the dorsal root entry zones during surgical manipulation may be responsible for the appearance of this complication.[82]

Hanbali and colleagues[54] reported that 56% of patients who were pain free prior to surgery developed moderate postoperative pain. Of 26 total patients in their series, 61% reported minimal pain within 4 weeks of their surgery, with 84% symptomatic within 6 months. Although the symptoms of dysesthetic syndrome tend to be refractory to medical therapy, they usually self-resolve within several months. However, McCormick and colleagues[82] reported that 2 of 23 patients remained symptomatic 1 year after surgery.

While preoperative dysesthesia has been identified as a predictive factor for postoperative dysesthetic syndrome,[82] Peker and colleagues[99] determined that intramedullary ependymoma length could also be used as a risk factor. As longer tumors require longer myelotomies, this increases the potential for dorsal column injury. In accordance with this theory, Epstein and colleagues[35] attempted to conduct atraumatic myelotomies, but were unable to attain a more significantly optimal outcome.

The impairment of bowel and bladder function is another neurological complication associated with spinal cord ependymomas, particularly seen in myxopapillary tumors originating at the conus medullaris.[53] McCormick and colleagues[82] reported that 5 of 23 patients experienced bowel and bladder dysfunction in the preoperative period. Three of these patients had conus tumors, 2 of which progressed to permanent worsening of the patients' dysfunction. Bagley and colleagues[8] examined neurological function in the pediatric population, reporting that 3 children developed bowel and bladder difficulties following their first, second, or third resection.

However, literature on pediatric spinal ependymomas suggests that the young population tends to have a favorable outcome, as 75%–93% of patients develop stable or improved postoperative neurological function.[23,33,83] Furthermore, it has been suggested that age may be a prognostic indicator, as a review of pediatric patients determined that the likelihood of postoperative neurological abnormalities increases by 9% for each increasing year in patient age.[57] It is speculated that similar to the developing brain, the pediatric spinal cord may possess an intrinsic level of plasticity with compensatory mechanisms to accommodate a limited degree of surgical disruption to native structures.[57]

Neurophysiological Monitoring

Given the possible complications related to the resection of spinal ependymoma tumors and their subsequent affect on postoperative function, various techniques of neurophysiological monitoring have been used to decrease surgical morbidity. Yanni and colleagues[135] reported results from their combined approach with intraoperative functional dorsal column mapping, preoperative radiographic imaging, and intraoperative ultrasonography to identify the most appropriate location for their midline myelotomy.[102,135] A miniature multielectrode spinal cord grid was used to define the amplitude gradient of conducted SSEPs following bilateral tibial nerve stimulation, thereby correlating the functional anatomy of the patient with the surgical anatomy of the dorsal column (Fig. 3).[79,135] These data were interpreted intraoperatively by the neurophysiology team to more precisely locate the optimal plane of dissection for their midline myelotomy and avoid neurological injury. In 7 of 10 patients, the midline could not be defined with certainty by anatomical means alone. However, the utilization of dorsal column mapping and other neurophysiological monitoring techniques resulted in unilateral posterior column dysfunction in only 2 patients.

Damage to the posterior columns due to either incision or retraction results in SSEP changes with decreased amplitude and/or increased latencies. In addition, MEPs and D-waves are also often advocated as useful neurophysiological monitoring techniques.[135] Motor evoked potentials are achieved following transcranial electrical motor cortex stimulation. The single stimulus technique elicits D-waves, allowing analysis of peak-to-peak amplitude using epidural electrode recordings. The multipulse stimulation approach evokes EMG feedback from the peripheral muscles. Potential injury to fibers of the motor pathways is indicated by loss of MEPs and/or decreased D-wave amplitude.[29] In such instances, irrigation with warm saline and elevation of mean arterial blood pressure to optimize spinal cord perfusion may allow potentials to recover.[135] Thus, intraoperative neurophysiological monitoring can potentially warn the surgeon of impending physiological deterioration of spinal cord integrity prior to irreversible neurological injury.[65]

However, some reports have failed to identify a statistically significant increase in prognosis with the utilization of neurophysiological monitoring techniques. In

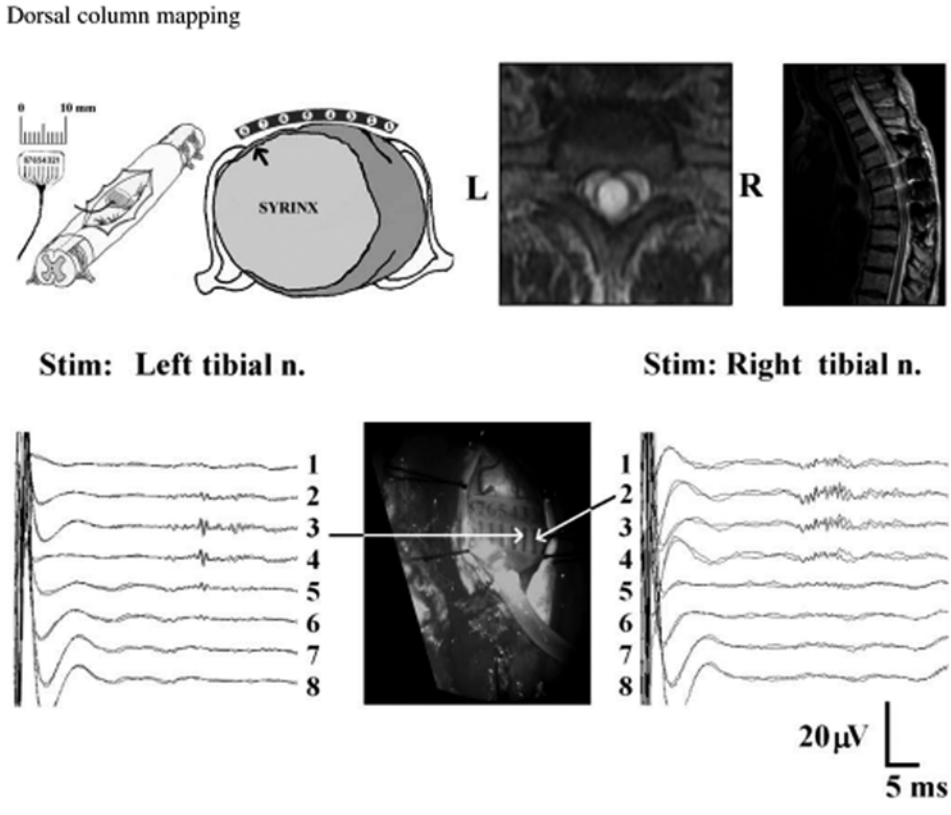


Fig. 3. Upper: Artistic depiction of the multielectrode grid used to identify the medullary midline in a patient with syrinx formation. **Lower:** Dorsal column mapping identifying the midline between markers 2 and 3. n. = nerve. Reprinted with permission from Yanni DS et al: **J Neurosurg Spine 12:**623–628, 2010.

their small study of 17 patients, Alkhani and colleagues[6] reported that patients did well regardless of monitoring status. As SSEP monitoring alone may result in false-negative responses and be insufficient for accurately predicting motor outcome, multimodal intraoperative monitoring is often recommended.[6,11,65,75,132] Aside from those already described, other methods include free running EMG, evoked EMG, compound muscle action potentials, and rectal/urinary sphincter EMG.[65,68,96,119] Again, while none of these modalities can independently provide a holistic evaluation of spinal cord and root integrity, their use in combination can allow surgeons to proceed with enhanced precision and confidence that the risks of neurological damage have been minimized.[65]

While the advantages of neurophysiological monitoring have been demonstrated in a number of studies regarding thoracolumbar spinal lesions, data regarding its use for operations involving the cervical spine are limited.[3,31,50,65,69] Given the low incidence of new postoperative neurological deficits for surgeries in this region, SSEP inaccuracy and suboptimal sensitivity make this a poor choice for single-modality monitoring.[65,75] In fact, isolated injury to the motor tracks with sparing of the sensory pathways may allow false-negative responses and result in postoperative deficits.[65,132] Although MEPs can offer superior sensitivity and specificity for evaluating motor integrity, MEP monitoring is more technically challenging than SSEP monitoring. Additionally, EMG monitoring is also considered a very sensitive technique, but it lacks specificity.[50,65,69] Given the potentially devastating impact of a neurological injury at the cervical level, Kelleher and colleagues[65] recommended intraoperative monitoring in all operations with neurological risk despite the low incidence of neurological complications. As no single monitoring modality appears optimal alone, multimodal monitoring may be the best approach. This is particularly applicable for patients with preexisting cord deterioration, as this population has demonstrated a higher risk for intraoperative cord compromise.[65,73,125] As the utilization of SSEPs in conjunction with either continuous EMG activity or MEPs can detect most intraoperative cord injuries, their implementation in concert provide independent and complementary feedback to enhance surgical precision, decision-making strategies, and patient safety.

However, a limitation of neurophysiological monitoring is the inherent inability to accurately record data from the spinal cord with severe preoperative dysfunction seen in patients with myelopathy, trauma, or intramedullary tumors. As these cases are the ones in which cord monitoring may be the most useful, further refinement of spinal cord monitoring techniques will be necessary to optimize surgical management in this population.[65]

Spinal Instability and Deformities

Another complication associated with surgery for spinal cord ependymomas is spinal instability and de-

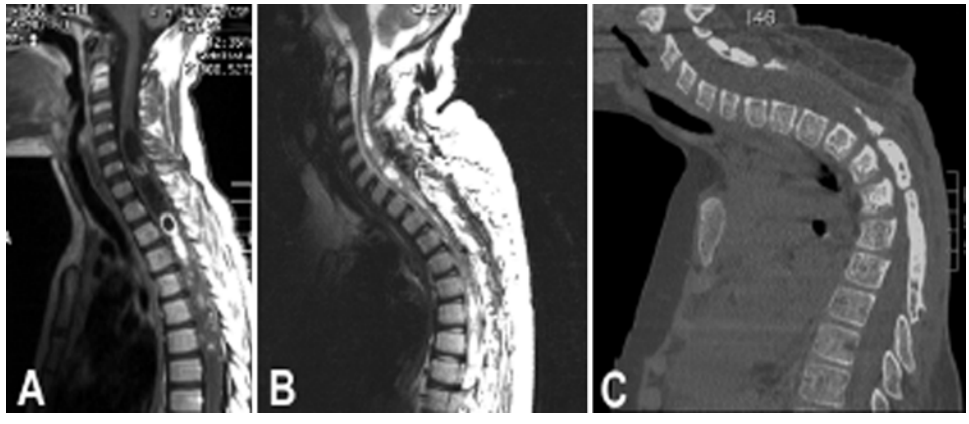


Fig. 4. Preoperative and postoperative images obtained in an 8-year-old boy who underwent 4 tumor resections with laminectomy for a spinal cord oligodendroglioma at the cervicothoracic junction. **A:** Initial sagittal MR image demonstrating normal cervical lordosis and a spinal cord tumor from C-3 to T-2. **B:** Sagittal T2-weighted MR image obtained after 2 tumor resections in 12 months revealing a kyphosis of 50° that developed at the cervicothoracic junction. **C:** Sagittal CT reconstruction image taken after 2 additional resections with laminectomy from C-4 to T-3 showing progression of kyphosis to 90° over the next 16 months. Reprinted with permission from Fassett DR et al: **Neurosurg Focus 20(2):**E2, 2006.

formities (Fig. 4). Postoperative kyphosis is of particular concern for tumors of the cervical and lumbar spine, as these regions lack a rib cage that can function as an internal brace providing biomechanical support for the thoracic levels.[77] Furthermore, the pediatric population is at an increased risk for progressive spinal deformities due to the horizontal orientation of their facet joints, a decreased elastic modulus (increased ligament laxity seen in children), and dynamic growth of the osseous spine.[39,95,107] Spinal cord tumor resection has resulted in spinal deformities in 16%–100% of pediatric patients[27,41,51,64,78,85,95,105,123,137,138] and up to 10% of adult cases.[26,34,39,85,95,116,120] These deformities may result in functional complications and necessitate future spinal fusions.[30,85]

Risk factors for developing a postoperative spinal deformity include prior resection, age younger than 13 years, surgical involvement of the thoracolumbar junction, syrinx formation, exposure to spinal radiotherapy, and preoperative scoliosis.[57,136] Being cognizant of these risk factors may allow surgeons to prevent such complications, detect the early onset of spinal instability, and mitigate neurological deterioration.

Historically, surgical procedures for spinal tumors included laminectomies to access the spinal cord, resulting in removal of the posterior osseous components.[57] This technique allows for a wide exposure and can be easily extended.[64,85] However, laminectomies can ventrally shift the weight-bearing axis of the normally lordotic cervical spine due to loss of the posterior ligamentous and osseous components. Consequently, the native curvature becomes straight and then progressively kyphotic as the anterior column becomes compressed and the posterior tension band fails to maintain the integrity necessary to preserve normal alignment.[35,39,47,74] In a cadaveric model, Nowinski and colleagues[92] reported significantly increased spinal instability following cervical laminectomy with more than 25% facetectomy as compared with patients undergoing laminoplasty procedures. Other studies have suggested that resection of more than 50% of the facet capsule alone may result in stability complications.[37] As such, to prevent spinal instability and deformity, surgeons should minimize resection of these crucial structures when possible.

To preserve these elements and optimize spinal stability, many surgeons began incorporating laminoplasty into their resections, which replaces bone and results in partial restoration of the posterior tension band.[1,27,58,85,103] However, studies on the efficacy of this technique to reduce spinal instability have produced inconclusive results. McGirt and colleagues[84] reported a study investigating the pediatric population and found that spinal deformities requiring fusion developed in 30% of patients who underwent laminectomy, compared with 5% of patients following the utilizing of laminoplasty.[57,84] Kucia and colleagues[70] reported 2 (7%) of 27 adults who developed spinal instability after resection of their intramedullary tumors with laminectomies, whereas none of their 40 adult patients who underwent laminoplasty developed such problems. However, in support of a 2003 meta-analysis in which the authors found no such discrepancy in postoperative spinal deformities between laminoplasty and laminectomy treatment groups,[104] in a series of 238 patients McGirt et al.[85] reported that the risk of spinal deformity was not significantly different between the two procedures regardless of tumor location (intramedullary vs extramedullary, cervical vs thoracic vs thoracolumbar), age, or preoperative misalignment (sagittal or coronal). However, their study was not sufficiently powered to address concerns of spinal instability beyond 2 years postoperatively. As such, future prospective studies with longer follow-up will be necessary to evaluate the long-term benefits of laminoplasty on spinal deformities.

For spinal ependymomas located in the ventral and lateral locations, a variant of the traditional surgical approach may be necessary. Lu and Lawton[77] reported a series of operations for intramedullary spinal cord cavernous malformations utilizing unilateral radical facetectomies and partial medial pedicle resections coupled with resection of the dentate ligaments to facilitate safe manipulation of the spinal cord and allow access to the ventral surface. They also noted that while radical facetectomy

may theoretically result in spinal instability, no such occurrence developed when this technique was executed unilaterally for a single level.

While controversial, the practice of prophylactic spinal fusion during the initial surgery may prevent progressive spinal deformities. In one series of 33 pediatric patients with intramedullary spinal cord tumors, Simon and colleagues[121] reported that 13 (62%) of 21 patients who received laminectomy or laminoplasty developed significant spinal deformities. Conversely, only 3 (25%) of 12 children who received spinal fusion at the time of initial surgery demonstrated similar instability. However, in a series of 22 adult patients, Lu and colleagues[77] did not observe any cases of spinal deformities following laminectomy, even when crossing the cervicothoracic or thoracolumbar junctions. As such, while spinal fusion is not necessary in every case, patients with significant risk factors for postoperative spinal instability may be good candidates for prophylactic spinal fusion.

From our experience, the decision to implement instrumentation in adults may rely on several factors, including preoperative spinal alignment, location of the tumor, and the levels of involvement. For tumors of the cervical spine, instrumented fusion is often performed for lesions spanning 3 or more spinal levels or in patients with preoperative kyphosis. In the lumbar spine, instrumented fusion is often not necessary if the laminectomy is performed without violation of the facet joints. However, in cases with significant preoperative spondylolisthesis and instability, instrumentation may be necessary. Furthermore, for large tumors of the thoracic spine, a posterolateral approach (transpedicular, costotransversectomy, or lateral extracavitary) may be optimal and necessitate subsequent fusion.

Adjuvant Therapy

Radiotherapy

While advances in the modern surgical approach to spinal ependymoma treatment have resulted in reduced morbidity and mortality, the role of postoperative radiotherapy continues to be controversial.[17,133]

Although there remains a great deal of debate regarding the utilization of postoperative radiation following gross-total resection of a spinal ependymoma, most current studies do not promote its application in this patient population as a necessary treatment.[7,33,57,62,67,70,74,80,87,93,117,118,129,133,139] However, Akyurek and colleagues[4] reported that in 35 cases of myxopapillary ependymomas, postoperative radiotherapy was able to decrease the rate of tumor progression, regardless of the extent of resection. In addition, Chao and colleagues[21] demonstrated that at the time of initial recurrence, radiation may be able to prolong the interval until subsequent recurrences. Given the rate of recurrence for spinal ependymomas treated with surgery alone and the success of radiation as a potential salvage therapy, Al-Halabi and colleagues[5] recommended that postoperative serial imaging be mandatory.

Conversely, radiotherapy following incomplete resections is generally recommended by most investigators.[45,60,66,111,114,131,139] Gavin Quigley and colleagues[44] examined neurological outcomes and found that 82% of their patients remained at baseline or achieved functional improvement with adjuvant radiotherapy following an incomplete resection, compared with 78% of patients with similar results who underwent complete resections of their tumors only. Several other studies have demonstrated improved survival, as well as decreased and delayed recurrence with the utilization of postoperative radiotherapy following incomplete resections.[7,22,45,67,111,114,117,118,122,128,129,131,139] In addition, patients with anaplastic ependymomas or severe metastatic disease may also be good candidates for adjuvant radiotherapy.[19,42,74]

However, the benefits of radiation therapy must be taken into consideration with a number of potential complications. Radiotherapy may result in reactive gliosis and fibrosis, hardening of the ependymoma, and disruption of the natural dissection planes. As radiation predisposes the ependymoma to increased adhesion to the spinal cord, reoperation for recurrence may be more difficult with increased morbidity.[54,130,133] Radiotherapy may also destroy microvasculature within the spinal cord, increasing the susceptibility of this already sensitive and diseased structure to further surgical perturbation.[133]

Radiotherapy can predispose patients to radiation myelopathy and ultimately result in severe neurological damage. This potential complication has been the limiting factor for the use of postoperative radiation at many surgical centers.[94,130,133] Pathological features of radiation myelopathy include asymmetrical demyelination of the lateral columns, coagulative necrosis, decreased glial response, and arteriolar wall proliferation. In rare cases, myelopathy can progress to lower motor neuron syndrome, characterized by irreversible muscle atrophy, bilateral weakness, and decreased reflexes.[36]

Some studies have suggested that total local radiation doses greater than 50 Gy may produce a more significant response.[34,94] In their retrospective study of 85 patients with myxopapillary ependymomas, Pica and colleagues[101] compared outcomes for patients undergoing surgery plus postoperative radiotherapy versus surgery alone. They concluded that the 5-year PFS was 82% for patients who underwent surgery plus postoperative high-dose radiotherapy, compared with 50% for surgery alone. Furthermore, there was no difference in 5-year PFS between those receiving surgery alone or surgery plus low-dose radiotherapy. In accordance with a Mayo series,[101,112] they observed that high-dose radiotherapy (> 50.4 Gy) may possess greater benefits than lower doses. While these higher doses may increase the patient's risk for neurological impairments, it has been estimated that a patient receiving 55 Gy of radiation has a less than 2% risk of significant spinal cord injury.[45,113]

Since recurrence is predominantly a local phenomenon, prophylactic radiation exposure of the entire craniospinal axis may place the patient at an unnecessary risk for complications.[43,131] Furthermore, current recommendations indicate that radiotherapy targeting the complete spinal or craniospinal regions should generally be reserved for those with metastatic disease.[45]

The use of radiation therapy is a controversial, albeit promising, postoperative adjuvant therapy for spinal ependymomas, which will necessitate further studies to evalu-

ate its true potential. Current findings suggest that its primary application may be most valuable after incomplete resection and for anaplastic ependymomas, although its possible complications should be taken into consideration.

Chemotherapy

The use of chemotherapy for the treatment of spinal cord ependymomas has also been very limited, with most reports evaluating patients with recurrence. While some studies have failed to identify any associated benefit with the use of adjuvant chemotherapy,[9,10] other findings have been more encouraging. Chamberlain[18] reported chemotherapeutic results of 10 patients with recurrent spinal ependymomas who had previously undergone surgery and radiation. Two patients demonstrated partial responses following treatment with chronic oral etoposide, while another 5 patients maintained stable disease. Fakhrai et al.[38] reported clinical improvement and mild tumor regression in a patient with a platelet-derived growth factor receptor–positive spinal ependymoma treated with imatinib. Iunes and colleagues[61] discussed a patient receiving postoperative carboplatin and radiotherapy for their intradural extramedullary tumor with multifocal presentation; the patient survived 2 years. Dorr et al.[32] described a partial response to recombinant human interferon–α for 15 months in a patient with a spinal cord ependymoma, while Tan and colleagues[124] reported a 2.75-month clinical and radiological response following treatment with aziridinylbenzoquinone (AZQ). Although the heterogeneity of chemotherapies used in these studies precludes any definitive conclusion regarding their overall efficacy, adjuvant chemotherapy warrants further inspection as a promising management strategy of recurrent spinal ependymoma tumors.[12]

Leptomeningeal Dissemination

Data regarding the appropriate management for leptomeningeal dissemination associated with spinal ependymoma tumors are also severely limited. Parker and colleagues[97] reported a patient with a lumbar myxopapillary ependymoma and leptomeningeal metastasis treated with HT (TomoTherapy, Inc.). While CSI is often recommended for CNS malignancies with a proclivity for leptomeningeal spread,[86,97,98] the authors theorized that their HT technique may prove more effective due to the larger dose per fraction and higher total dose delivered to the boost sites compared with conventional CSI methods. Furthermore, HT is stated to decrease the complexity of treatment planning by avoiding issues of beam matching, junctions, and beam gaps that may occur during more traditional approaches. Lin et al.[76] presented a patient with a recurrent anaplastic ependymoma and leptomeningeal seeding managed with salvage therapy consisting of CSI with focal boost and oral chemotherapy with CCNU (1-(2-chloro-ethyl)-3-cyclohexyl-1-nitrosourea). This treatment resulted in relief of symptoms, improved quality of life, and a 34-month survival.

Cerebrospinal Fluid Leaks and Wound Infection

Any procedures involving intradural dissections have a heightened potential for postoperative CSF leaks.[57] Patients who have undergone radiotherapy or had previous operations are at an increased risk for this complication due to poor tissue integrity.[25,114] Hanbali et al.[54] reported 2 of 26 patients requiring lumbar drainage for CSF leaks, both of whom had undergone previous surgeries. Kucia and colleagues[70] noted 13% of 67 patients with either CSF leaks or pseudomeningocele who underwent lumbar drainage, wound revision, and/or lumboperitoneal shunting. Gavin Quigley and colleagues[44] reported 23% of 26 cases of postoperative CSF leaks, 2 of which led to culture-positive meningitis.

While meticulous primary closure of the dura is the best preventative measure, fibrin glue, laminoplasty, and lumbar drain placement may be used as prophylactic tactics.[57,109] In their study, Manzano et al.[79] used an expansile duraplasty and a lumbar drain to widen the subarachnoid space, divert CSF, and protect against CSF leaks. Furthermore, dead space may be reduced through the utilization of laminoplasty and multilayered closures to inhibit seepage through the skin. McGirt and colleagues[85] identified a trend associated with laminoplasty and decreased CSF leaks compared with resections involving laminectomies. They hypothesized that reclosure of the paraspinous muscles to the spinous processes in conjunction with the replacement of laminae may aid in CSF containment. While a lumbar drain, bedrest, oversewing the incision, and tissue adhesives may be sufficient to allow for proper healing of the skin and subcutaneous tissues, a wound revision with primary closure of the dural defect may be ultimately necessary.[57]

Similar to CSF leaks, wound infections are also more prominent in patients with a history of prior surgeries or radiotherapy.[114] While this complication is a consideration of many other surgical procedures, it may be theorized that, given the sensory deficits of spinal ependymoma patients, this population may require more attentive detail in their postoperative care. Kucia and colleagues[70] reported that 9% of their patients required antibiotics and/or wound debridement for wound infections. McCormick et al.[81] noted that 17% of 23 patients experienced complications related to wound infections.

Conclusions

Despite the advances in microsurgical techniques and intraoperative cord monitoring modalities, there remain a number of serious complications related to the treatment of spinal ependymoma tumors. Identification and acknowledgment of these potential problems may assist in their prevention, early detection, and increased quality of life for patients afflicted with this disease.

Disclosure

Daniel Nagasawa was partially supported by an American Brain Tumor Association grant. Isaac Yang (senior author) was partially supported by a Visionary Fund Grant and a UCLA Stein Oppenheimer grant.

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: all authors. Critically revising the article: Yang, Nagasawa, Smith, Cremer, Lu. Reviewed submitted version of manuscript: Yang, Nagasawa, Smith, Lu. Approved the final version of the manuscript on behalf of all authors: Yang. Statistical analysis: Yang, Nagasawa. Administrative/technical/material support: Yang, Nagasawa, Smith, Lu. Study supervision: Yang, Nagasawa, Smith, Cremer, Lu.

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Manuscript submitted June 15, 2011.
Accepted July 19, 2011.

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Neurosurg Focus 31 (4):E14, 2011

Management considerations and strategies to avoid complications associated with the thoracoscopic approach for corpectomy

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The thoracoscopic approach to the anterior spine is a practical and valuable means of approaching ventral spinal lesions but demands advanced technical skills and fine hand-eye coordination that is usually acquired with experience. A mutual understanding of all the ventilatory and surgical steps allows for an organized orchestration between the anesthesiologist and surgeon, which ultimately helps minimize potential complications. Despite a concerted effort by all involved to avoid risks, thoracoscopic surgery is associated with complications for which the surgical team should be cognizant. In this paper, the authors detail the operative technique of vertebral corpectomy and interbody fusion via the thoracoscopic approach for the treatment of ventral spinal pathology involving the thoracic and lower lumbar spine, discuss complications known to occur with the thoracoscopic approach, and present means to help avoid them. *(DOI: 10.3171/2011.8.FOCUS11133)*

Key Words • **video-assisted thoracoscopy** • **double-lumen endotracheal tube** • **thoracotomy** • **barotrauma** • **minimally invasive corpectomy**

The use of the thoracoscopic approach to the thoracic and upper lumbar spine for anterior corpectomy has increased since its introduction in the early 1990s. Jacobaeus[10] was the first to describe the use of the thoracoscopic approach to the chest in 1910 (Fig. 1). By the late 1980s, cardiothoracic surgeons had developed the video-assisted thoracoscopy, which attracted the attention of spine surgeons Lewis and Obenchain, who ingeniously incorporated this technique to target ventral spinal disease.[14,16] Compared with its predecessor (open thoracotomy), the thoracoscopic approach affords better cosmetic results, less postoperative pain, earlier mobilization, shorter hospital stays, and lower treatment costs.[8,14] In addition, the commonly encountered perioperative morbidities associated with open thoracotomy, such as pneumothorax, pleural effusions, chylothorax, pneumonia, and intercostal neuralgia, are substantially reduced with the endoscopic method.[8] Moreover, thoracoscopy avoids shoulder girdle dysfunction, which was commonly encountered with the open approach because of the need for large incisions and excessive and prolonged rib cage retraction.[7]

Despite the success of the thoracoscopic approach in reducing many of the problems associated with open thoracotomy, it is not without complications. Since thoracoscopic spine surgery is a challenging undertaking that calls on the surgeon to have excellent hand-eye coordination in an enclosed space where depth perception is hampered, complications can result from a lack of experience. There are also unavoidable complications that can arise in the hands of even the best-trained surgeons, and some complications are associated with anterior approaches in general and are not unique to thoracoscopic surgery. In this paper, we delineate the operative technique of thoracoscopic corpectomy and interbody fusion of the lower thoracic and upper lumbar spine in a step-by-step manner and emphasize its risks and present suggestions on how to avoid them.

Operative Technique

Proper operative technique starts with ensuring correct patient positioning and operative staff setup to afford a more efficient and comfortable working environment. The operating room should be arranged in a way that allows for effortless handling of instruments, comfortable working distance, and simple screen visualization for the surgeons while providing the anesthesiologist with easy and unhindered access to the patient's airway (Fig. 2). Typically, the room is set up with the main surgeon



Fig. 1. H. C. Jacobaeus of Stockholm using an early cystoscope to peer through a patient's pleural cavity. Reprinted with permission from **Archives of Surgery 139 (1):**100–112, 2004. Copyright 2004 American Medical Association. All rights reserved.

standing directly behind the patient and the operative site. The assistant operating the endoscope stands to the right of the main surgeon. The scrub nurse stands across from the main surgeon facing the patient. A video monitor displaying the endoscopic image is placed in front of the patient across from the main surgeon, and, when available, a second video monitor is placed behind the patient across from the scrub nurse or second assistant. A fluoroscopic monitor is placed beside the endoscopic monitor across from the main surgeon.

Highly specialized minimally invasive thoracoscopic instruments with appropriate length for easy maneuverability and nonreflective surfaces for thoracoscopic surgery have been developed. In addition, minimally invasive thoracoscopic instrumentation has been specifically developed for anterior column stabilization and preservation of spinal alignment after a corpectomy. The MACS-TL anterolateral thoracolumbar spinal implant (Aesculap) was specifically designed for this purpose. It consists of a rigid plate that sits along the anterolateral aspect of the vertebra spanning 1 segment above and below the fractured level, with a ventral hole for an anterior stabilizing screw and a dorsal hole for a posterior polyaxial screw at the ends of the plate. The screws are implanted into the normal vertebrae below and above the diseased level. The posterior polyaxial screws are placed first, starting with the caudal end, to maintain adequate working visibility. The biomechanical properties of this plating system have been tested in single- and multilevel, partial and full corpectomy models with and without posterior ligamentous injury, and its efficiency has been demonstrated in many case series.[11,12,20–23]

After the patient has been positioned properly, the portals have been placed, and the diaphragmatic incision has been made to expose the pathological vertebra as detailed in the following sections of the paper, the screws are placed in preparation for the corpectomy and final interbody construct. Before the polyaxial screw is placed for the MACS-TL plating system, a short K-wire is inserted into the level caudal to the fractured vertebra 10 mm anterior to the spinal canal and 10 mm away from the superior endplate in the upper third of the vertebral body (Fig. 3A). It is inserted under fluoroscopic guidance

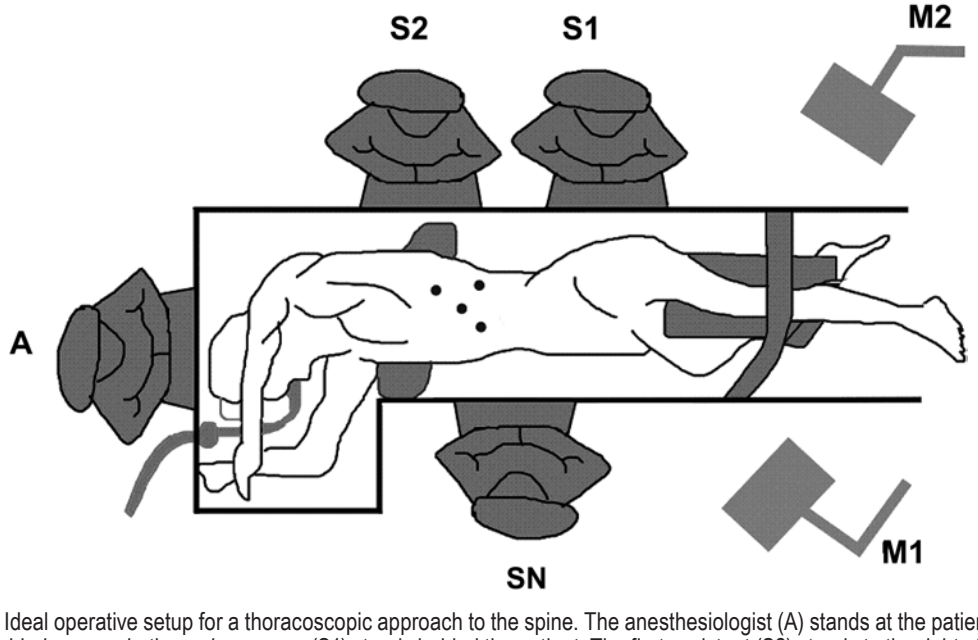


Fig. 2. Ideal operative setup for a thoracoscopic approach to the spine. The anesthesiologist (A) stands at the patient's head. For a left-sided approach, the main surgeon (S1) stands behind the patient. The first assistant (S2) stands to the right of the main surgeon and operates the endoscope while the scrub nurse (SN) stands opposite the surgeons. Video monitors (M1 and M2) display the endoscopic image.

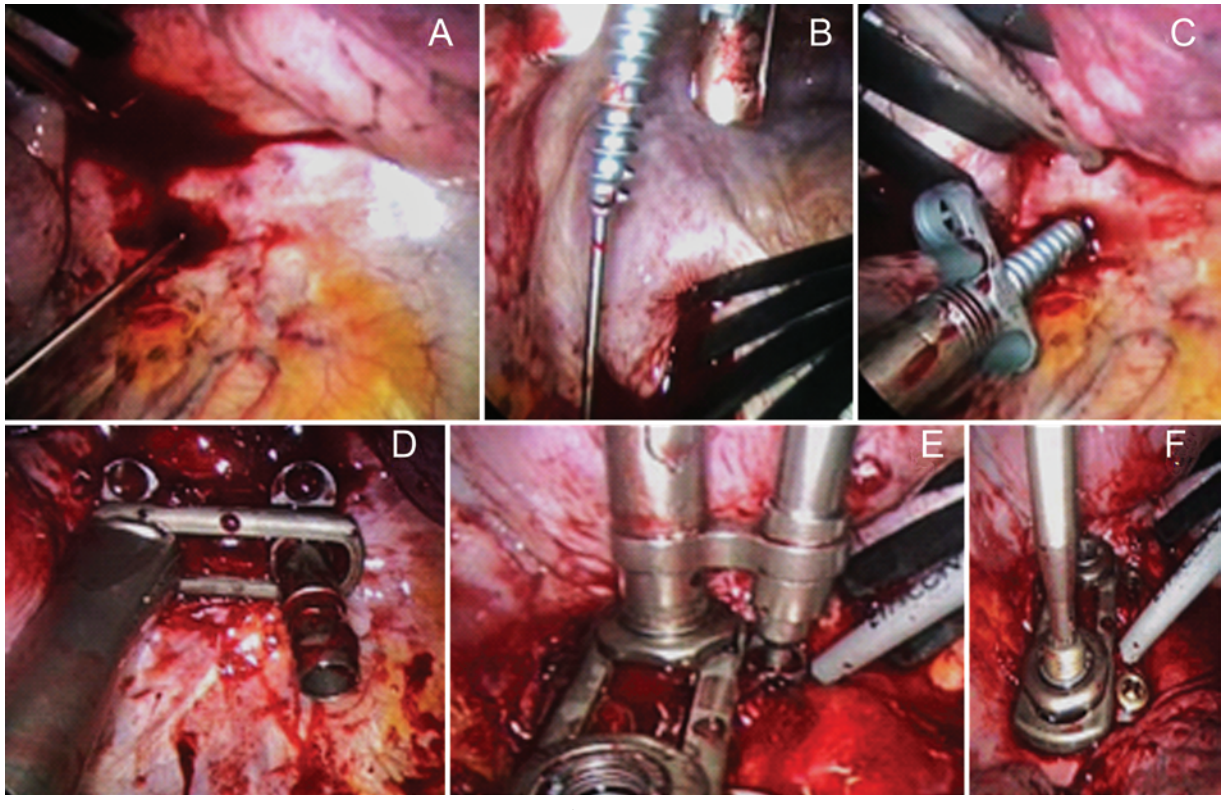


Fig. 3. Intraoperative photographs showing placement of the plating system. The K-wire is inserted into the level caudal to the fractured vertebra 10 mm anterior to the spinal canal and 10 mm away from superior endplate in the upper third of the vertebral body **(A)**. The polyaxial screw–clamp assembly is then attached to a centralizer tube and inserted over the K-wire **(B and C)**. After placement of the polyaxial screw–clamp assembly in the upper vertebral body superior to the fracture level and after completing the corpectomy and placement of an interbody cage with morcellized bone, the anterolateral interbody plate is placed **(D and E)**. Finally, fixation nuts are placed on the polyaxial heads and tightened with a torque device **(F)**.

perpendicular to the cortical surface with a radiolucent targeting device that has concentric rings that align once a perpendicular position is achieved. A mallet is used to impact the device attached to the K-wire until a depth of 25 mm is reached. Next, a cannulated decorticator is inserted over the K-wire to perforate the cortical surface and allow for subsequent screw placement. The polyaxial screw is inserted into a specialized polyaxial clamp. This assembly is then attached to a centralizer tube and inserted over the K-wire (Fig. 3B and C). The clamp is positioned so that the hole for the anterior stabilizing screw is ventral to the hole for the polyaxial screw. The polyaxial screw is then slowly inserted over the K-wire, which is removed after the screw is past the cortical surface. The screw is then slowly advanced to its full depth. The cranial polyaxial screw is inserted in a similar fashion. The anterior and posterior edges of the clamps help define the anteromedial and posterolateral extent of the corpectomy. The superior and inferior boundaries of the corpectomy are defined by intervertebral disc spaces above and below the diseased level. An anulectomy of the superior and inferior discs is then performed, followed by disc resection with the use of thoracoscopic rongeurs. As for the corpectomy, a thoracoscopic rongeur is used to remove the central bone. The space left behind after the bone resection is molded into a rectangular fashion with the use of osteotomes to accommodate the subsequent interbody cage. The final depth of the corpectomy is confirmed using fluoroscopy (Fig. 4).

For retropulsed bone or spinal disease extending past the posterior border of the vertebral body into the spinal canal, the spinal canal is decompressed. This may be done by resecting the pedicle on the involved end. The pedicle is accessed by following the rib head to its attachment to the anterolateral spine and resected using a high-speed drill. Removal of the proximal 2 cm of the rib exposes the underlying pedicle, which may be felt with a blunt hook. The pedicle is then resected using a high-speed drill and rongeurs to decompress the neural foramen and provide access to the dorsal epidural space to remove any retropulsed bone fragments or tumor.

For the interbody implant, we use an expandable titanium cage with appropriate dimensions based on careful measurements obtained using a caliper. At this stage, the operative portal is replaced with an expandable speculum to allow for ease of access when passing the expandable cage into the interbody cavity. Morcellized bone autograft is used in and around the cage to help promote fusion. The anterolateral interbody plate is placed after the interbody cage (Fig. 3D and E). The plate length is determined by measuring the distance between the screw heads on either end of the vertebral body and adding 30 mm. The plate is first placed on the centralizer and caudal screw–clamp assembly and then placed onto the cranial

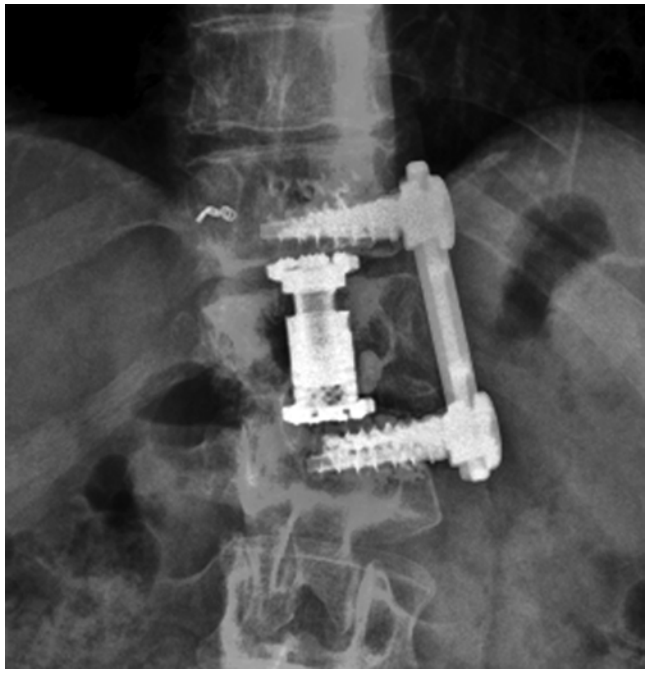


Fig. 4. Anteroposterior upright radiograph of the thoracolumbar junction showing a T-12 interbody cage following a T-12 corpectomy with lateral vertebral body plate and screw fixation. Reprinted with permission. Copyright Department of Neurosurgery, University of Utah.

assembly. The posterior polyaxial screws are left slightly loose at first for easy plate manipulation to help facilitate plate positioning. The fixation nuts are then placed on the polyaxial heads and tightened with a torque device (Fig. 3F). Anterior stabilizing screws are inserted through the ventral hole after the bone is decorticated. The anterior screws should be 5 mm shorter than the posterior polyaxial screws to prevent contact of the 2 screws. Finally, lateral and anteroposterior fluoroscopic images help verify the final construct position.

Complications

The incidence of complications with thoracoscopic surgery is generally low and may be avoided with careful perioperative planning and consideration for the potential risks involved with every step from intubation to closure and extubation (Table 1).

Pulmonary and Anesthesia-Related Complications

Single-lung ventilation is of crucial importance to the success of thoracoscopic spine surgery. Whereas in open, mini-open, or retropleural approaches, the ventilated lung can be retracted to expand the operative field, it is not possible to do so with thoracoscopy. In addition, the operating times and thus the length of time the lung is excluded from ventilation are frequently longer than for other thoracoscopic procedures.

Single-lung ventilation with a double-lumen endotracheal tube ventilating the contralateral lung while collapsing the ipsilateral one carries risks of which the operating team should be aware. For instance, incorrect tube placement, inaccurate tube size, and over- or underinflation of the bronchial cuff lodged in the mainstem bronchus of the ipsilateral lung can lead to air leaks into the operated lung. Inadvertent injury to a vein during positive-pressure insufflations can lead to carbon dioxide embolism with potentially fatal cardiac and neurological sequelae.[18] Preoperative imaging, a detailed physical examination, and medical history can reveal important information about the patient's fitness for this surgery. For instance, the presence of blebs on a CT scan of the chest or a known history of a medical condition that increases the patient's risk of developing pneumothorax, such as chronic obstructive pulmonary disease or Marfan syndrome, can alert the anesthesiologist to the patient's heightened chance of experiencing such a complication. In the latter scenario, a pneumothorax caused by the rupture of an alveolar bleb could result in hypercarbia and hemodynamic instability. Another concern is the iatrogenically created ventilation-perfusion mismatch that can occur when both lungs are being perfused while only ventilating the nonoperative lung; this can lead to arterial desaturation over an extended period of time.[3,16] In addition, the ventilation-perfusion mismatch may lead to inefficient CO_2 clearance with subsequent CO_2 retention and acidemia. This ventilatory practice of continuous prolonged nonventilation of the ipsilateral operative lung also allows for excessive accumulation of secretions in the airways resulting in atelectasis and pneumonia.[3,16,18]

Complications Related to Positioning

Proper patient positioning is important for ensuring a safe and unproblematic approach to the lateral aspect of the vertebral body and for preventing skin breakdown. The patient is usually placed in a right lateral decubitus position with his or her left side up, but ultimately the side of the approach is selected based on the pathological condition and the position of the aorta as determined from preoperative CT images. We favor approaching the spine through the left side to prevent injury to the inferior vena cava and to afford increased working space that is otherwise hindered by the presence of the liver on the right. With this positioning, liver injury from excessive retraction is also averted. The operating table is left in a flat position with the sagittal plane of the patient's body parallel to the ground. This latter position permits direct access to the vertebral body in question and minimizes anatomical errors. Despite its usefulness in providing excellent visualization and allowing for ease of work, the lateral decubitus position has its complications. Pressure can be exerted on the brachial plexus either directly on the side on which the patient is lying or by over-abducting the arm on the side of the operation. Similarly, the peroneal nerve may become compressed at the fibular head, resulting in a foot drop postoperatively. Also, prolonged operative time without appropriate padding may lead to the development of pressure ulcers and muscle breakdown with subsequent rhabdomyolysis and renal failure.[18]

The surgical staff arrangement in the operating room described above is just as important as the patient setup for ensuring an efficient and comfortable working environment.

TABLE 1: Complications of thoracoscopic surgery and potential avoidance strategies*

Complication Type	Complications	Suggested Complication Avoidance Strategies
anesthesia	incorrect ETT placement inaccurate ETT size over- or underinflation of bronchial cuff CO_2 embolism pneumothorax ventilation-perfusion mismatch acidemia accumulation of secretions	preop PFT & ABG; CPAP on nonventilated lung; postop respiratory therapy; recheck position of double-lumen ETT w/ bronchoscope prior to op & any time oxygen saturation drops below 90%; ensure adequate inflation of bronchial & tracheal cuffs
positioning	brachial plexopathy foot drop pressure ulcers muscle breakdown rhabdomyolysis	proper padding on all pressure points; U-shaped gel foam between legs
instruments	injury to lungs injury to large vessels diaphragmatic injury breakage of tools w/in chest cavity skin burns diaphragmatic hernia pneumomediastinum & pneumoperitoneum subcutaneous emphysema	digital sweeping of portal site prior to port placement; fluoroscopic projection of op site onto skin for target portal incision & planning of remaining portal sites; initial placement of endoscopic port farthest away from diaphragm; K-wire insertion prior to screw placement; lunar diaphragmatic incision; adequate time for lung reinflation & evacuation of entrapped air prior to removal of portals
hemodynamic	excessive intraop bleeding prolonged op time abundant use of suction splenic rupture tension pneumothorax	limit use of suction when able; intraop hypotensive anesthesia; ensure adequate hemostasis; preop screening for primary lung disease; careful handling of instruments; limit retraction on spleen; experience (reduces op time)

* ABG = arterial blood gas; CPAP = continuous positive airway pressure; ETT = endotracheal tube; PFT = pulmonary function test.

Complications Related to the Use, Placement, and Removal of Instruments

Injury to large intrathoracic vessels can occur with instrumentation in a variety of ways. Endoscopic instruments placed in the intrapleural cavity can cause injury to the lung parenchyma and large vessels in the chest cavity, leading to air leaks postoperatively and excessive blood loss intraoperatively.[3,16,18] The bleeding can come from epidural veins, tumor-feeding arteries, large segmental vessels, and intercostal vessels. In many instances, considerable blood loss is a result of poor coagulation due to inadequate exposure. The initial blind placement of the endoscope prior to placement of the instrument trocars also poses a risk of direct injury to the lung, diaphragm, and intercostal vessels. The latter complication may be a result of lung adhesions bringing the lung parenchyma closer to the skin surface than anticipated.[16] The surgeon should place the trocars as gently as possible so as not to place pressure on the intercostal nerves, which could result in intercostal neuralgia. Once the trocars are placed, the surgeon should verify that they have crossed all tissue layers into the pleural cavity so as not to cause subcutaneous or mediastinal emphysema.[7,9,18]

Careful handling of the endoscope and endoscopic instruments is important. Surgical tools within the chest cavity can bend or break with forceful use. With the endoscope, the surgeon should keep in mind that the tip can get hot and should therefore be placed aiming upward when outside the thoracic cavity to prevent burns.[16,18] The need for proper handling of instruments is exemplified by the gentle nerve root retraction necessary during nerve root decompression from a burst fracture when performing a corpectomy.[24]

The diaphragmatic incision necessary to gain access to the retroperitoneal section of the thoracolumbar junction, for instance, may predispose a patient to the development of a diaphragmatic hernia postoperatively, especially if the incision is made in a radial fashion. A radial incision in direct proximity to the orifices of the esophagus and aorta weakens the diaphragm fixation and causes the resected margins to separate with increased intraabdominal pressure. It is our preference to place a

small semilunar incision into the diaphragm parallel to the disc space and not in line with the spine.[13]

Another interesting complication that can occur with the improper handling of instruments was discussed by Garcia et al.,[5] who presented the case of a 73-year-old woman who developed bilateral pneumothoraxes, pneumomediastinum, pneumoperitoneum, and subcutaneous emphysema after thoracoscopic anterior stabilization of a T-12 compression fracture because of intraoperative air entrapment. The authors asserted that the diffuse spread of air within the viscera was not due to barotrauma since a pressure limitation of 22 cm H_2O was maintained throughout mechanical ventilation. Animal studies have shown that a pressure of 50 cm H_2O is required for the development of pneumomediastinum and pneumothorax.[6] Upon insufflation of the collapsed lung at the conclusion of the case and with expansion of both lobes, the intrathoracic air is normally pushed out through the chest tube and the thoracoscopic portals. Garcia et al.[5] noted, however, that in their case, the premature removal of the portals and a likely obstruction in the chest tube may have trapped air within the chest cavity, increasing intrathoracic pressure and allowing air to pass through the pleural incision and the diaphragmatic split.

Hemodynamic and Vascular Complications

Excessive intraoperative bleeding results from prolonged operative time and is usually due to oozing from the epidural venous plexus and segmental arteries, especially when treating burst fractures. The thoracoscopic approach has lessened the amount of intraoperative blood loss encountered. When Ragel et al.[19] compared thoracoscopic procedures with open thoracotomy corpectomies, they demonstrated a statistically significant decrease in blood transfusion requirement. However, despite the dramatic decrease in the amount of blood loss afforded by the thoracoscopic approach, bleeding is inevitable and is of concern especially with prolonged operative time. Watanabe et al.[24] noted the learning curve with thoracoscopic surgery whereby experience with the technique usually reduces operative time and blood loss, averting the need for blood transfusion. Extensive bleeding was reduced from 31.6% of cases to 3.0% after 4 years of experience. Interestingly, the volume of blood loss was directly related to the duration of operation. The average operative time and blood loss decreased from 540 to 300 minutes and from 4.0 to 1.5 L, respectively, over the 4-year period. Increased blood loss could lead to hemodynamic instability, necessitating intravascular expansion with crystalloids and blood transfusion. Being cognizant of the amount of actual blood loss is equally important for both the anesthesiologist and surgeon. Predicting the current as well as the anticipated blood loss allows the anesthesiologist to plan ahead and therefore arrange for the transfusion of blood products as needed and to carry out careful intraoperative hypotensive anesthesia preemptively in an effort to reduce blood loss and minimize the need for transfusion.[9] Huang et al.[9] reported that intraoperative hypotensive anesthesia helped reduce excessive blood loss. For the surgeon, a sound knowledge of the vascular anatomy, careful handling of instruments, and affording adequate working space can help minimize blood loss. Moreover, limiting the excessive use of suction may also be helpful in reducing bleeding.[7,16]

In cases in which there is hemodynamic instability with no apparent source of bleeding, a high suspicion for retraction injury to the spleen is merited. Binning et al.[2] reported a case of a 60-year-old man who became hemodynamically unstable with no obvious source of bleeding during a thoracoscopic approach for a T-12 corpectomy. His postoperative abdominal CT scan was consistent with a splenic rupture necessitating emergency splenectomy. This was believed to be a result of diaphragm retraction throughout the case in a morbidly obese patient. Another potential source of hemodynamic compromise in the absence of obvious blood loss or ongoing bleeding is tension pneumothorax, either iatrogenically through inadvertent puncturing of the lung or spontaneously. This can compromise venous return and therefore cardiac filling and stroke volume, resulting in a precipitous decrease in blood pressure. Immediate attention is warranted to prevent a cardiac arrest.

Neurosurgical Complications

The dura mater is another structure that may also be inadvertently punctured, resulting in a CSF leak. With a dural rent, immediate repair is warranted to prevent postoperative spinal headaches and meningitis, especially in the presence of a chest tube, which can exacerbate the leakage due to the negative pressure. In such a case, the patient should be kept flat for at least 24 hours, and the chest tube should not be connected to suction.

Complication Avoidance

In light of the aforementioned complications, the surgeon should be highly cognizant of the risks involved with every intervention. Patients with known lung disease should undergo preoperative pulmonary function tests and arterial blood gas evaluation. Continuous positive airway pressure on the nonventilated lung can help prevent atelectasis, as can adequate postoperative respiratory therapy.[4,18] The position of the double-lumen endotracheal tube should be rechecked with a bronchoscope prior to proceeding with surgery and any time the arterial oxygen saturation decreases to below 90%.[18] Proper padding by placing gel rolls and foam pads over all pressure points can help prevent brachial plexopathy as well as peripheral nerve palsies.[15–18] When padding the legs, a special U-shaped gel foam keeps them well cushioned and spaced. This also helps prevent psoas muscle tightening, which could otherwise make retraction more difficult and thus hinder visibility. To avoid injury to the lung parenchyma and postoperative air leaks during initial port placement for the endoscope, digital sweeping movement through the planned port site as well as the use of an endoshear can be helpful.[5,18] The first port is placed farthest away from the diaphragm, and we use a "mini-thoracotomy" technique that allows for a direct view to inspect the chest cavity. After the first port has been placed, all other ports are placed under direct endoscopic vision. This avoids any "blind" placement of trocars in the chest cavity. The localization and placement of the portals

should be done in a careful and stepwise manner to minimize the chance for injury.[1] In the case of a thoracic corpectomy, the target (fractured vertebra) is projected onto the skin level using fluoroscopy, and the inferior and superior vertebral margins of the subjacent superior and inferior levels are marked out, respectively. The working portal is centered over the target vertebra. This access site usually extends 3–4 cm in length and should be large enough to insert the fusion instrumentation during the case. The endoscope channel is placed 2 or 3 intercostal spaces cranial to the target. Trocars for suction/irrigation and retraction are placed 5 and 10 cm anterior to the working and optical channels, respectively (Fig. 5). To avoid injury to the diaphragm, lungs, blood vessels, and nearby organs, the endoscopic or optical portal is inserted first so that the remaining portals may be inserted and removed under direct endoscopic vision.

Working within the confines of the thoracic cavity through projected endoscopic vision may be visually deceiving because of the lack of 3D vision. To facilitate orientation at the operative site, K-wires and polyaxial clamps are placed early on in the case through the lateral side of the inferior and superior aspect of the vertebral bodies above and below the fractured level, respectively. The clamps, in essence, act as landmarks for defining the superior and inferior extents of the spine. Furthermore, they help define the entry points for subsequent screw placement and ensure a perpendicular trajectory (Fig. 6). The caudal-segment K-wire is placed first so the visual field is not obstructed, and then the cranial-level K-wire is placed in the same fashion.

Anatomical consideration of the pattern of attachment of the diaphragm to the spine and ribs at the thoracolumbar junction is important. Instead of a radial incision, a lunar or semicircular incision that runs in line with the direction of attachments of the diaphragm helps avoid the late occurrence of a diaphragmatic hernia. An increase in intraabdominal pressure from a semicircular incision parallel to the dome-shaped attachment of the diaphragm causes the resected margins to come together instead of gaping as with the previously mentioned radial incision.

Since soft-tissue pressure of only 5 cm H_2O allows air passage between the mediastinum, the abdominal cavity, the thoracic cavity, and the retroperitoneum, surgeons should take ample time during reventilation of the collapsed lung to allow for evacuation of the entrapped air before the trocars are pulled out. Once the trocars are removed, the surgeon should check for bleeding at the port site by using the endoscope. Apparent bleeding can be controlled with bipolar coagulation or clip ligation. With severe bleeding, a Foley catheter can be inserted through the port site and inflated to help tamponade the bleeding.[5] Throughout the case, the surgeon should keep in mind that splenic injury and rupture is possible with excessive and forced retraction. If the patient is hemodynamically unstable and the operative field appears to be dry, the likelihood of a splenic injury should be entertained.

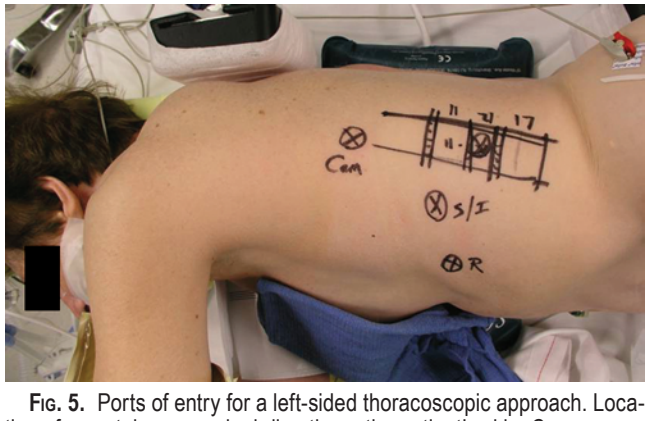


Fig. 5. Ports of entry for a left-sided thoracoscopic approach. Locations for portals are marked directly on the patient's skin. Cam = camera; R = retractor; S/I = suction/irrigation. Reprinted with permission from Amini et al: **Neurosurg Focus 19(6):**E4, 2005.



Fig. 6. Insertion of the screw and clamps over the K-wire creates a boxlike "safety zone" that helps define the superior and inferior extents of the concerned spinal segment. Reprinted with permission. Copyright Department of Neurosurgery, University of Utah.

Conclusions

The thoracoscopic approach to the anterior thoracic and upper lumbar spine is an innovative technique that avoids many of the risks and complications of open thoracotomy. With the careful handling of endoscopic instruments, limited use of retraction, operative experience, and a multidisciplinary approach involving the surgical staff and the anesthesia team, many of the potential complications can be circumvented.

Disclosure

Dr. Schmidt is a consultant for Aesculap.

Author contributions to the study and manuscript preparation include the following. Conception and design: Schmidt. Acquisition of data: Krisht. Analysis and interpretation of data: Krisht. Drafting the article: Krisht. Critically revising the article: Mumert. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Schmidt.

Acknowledgment

The authors thank Kristin Kraus, M.Sc., for editorial assistance in the preparation of this paper.

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Manuscript submitted June 14, 2011.
Accepted August 2, 2011.

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Neurosurg Focus 31 (4):E15, 2011

Management of incidental durotomy in minimally invasive spine surgery

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Object. Unintended durotomy is one of the most common complications in spine surgery that may lead to serious complications if not recognized or treated properly. There are few reports on the management of durotomies incurred during minimally invasive spine surgery (MISS). The authors describe their experience in a series of consecutive MISS patients with unintended durotomies.

Methods. All patients who underwent MISS by the senior author between August 2006 and February 2011 were retrospectively reviewed, and cases with unintended durotomies were identified. A case-control study was carried out comparing patient demographics and perioperative data between patients with and without durotomy. Surgical technique, including a proposed algorithm for management of durotomies, is described.

Results. Unintended durotomy occurred in 53 (9.4%) of 563 patients. The mean age at surgery was 60.7 years (range 30–85 years). Previous surgery at the same level was performed in 5 patients (9.4%). Two patients underwent posterior cervical surgery, and 51 patients underwent posterior lumbar surgery. Decompression alone was performed in 32 patients (60.4%), and fusion was performed in 21 patients (39.6%). The mean operative time was 105 minutes in the decompression group and 310 minutes in the fusion group ($p < 0.001$). Estimated blood loss was 60 ml in the decompression group and 381 ml in the fusion group ($p < 0.001$). The hospital length of stay was 52 hours in the decompression group and 106 hours in the fusion group ($p < 0.001$). The mean follow-up was 310 days, and there were no cases of cutaneous CSF fistula, pseudomeningocele, or other complications referable to durotomy in either group. Risk factors identified for durotomy included previous operation at the same level ($p = 0.019$) and operation in the lumbar spine region ($p = 0.001$).

Conclusions. In the authors' consecutive series of patients undergoing MISS, an unintended durotomy was associated with fewer complications than previously reported for open spinal surgery. The authors propose a simple management algorithm that includes early mobilization and results in excellent clinical outcomes with no incidence of postoperative cutaneous CSF fistula or other complications. *(DOI: 10.3171/2011.7.FOCUS11122)*

Key Words • **durotomy** • **minimally invasive spine surgery** • **complication**

Unintended durotomy is one of the most common complications in spine surgery, with a reported incidence ranging from 1.6% to 17.4%.[1,4,11,12,19,21,30,31,35–40,42] If not recognized or properly treated, it may lead to a persistent CSF leak and formation of a pseudomeningocele or cutaneous CSF fistula, with the resultant symptoms of postural headache, nausea, and back pain.[3,4,7,11,21,31,39] More serious complications include neurological deficit, meningitis, and intracranial hemorrhage.[4,5,7,11,14,20,23–28,34,42]

Although there have been several reports on perioperative management of durotomy in open spinal procedures,[3,4,11,15,21,36,39] there is a paucity of similar reports in MISS.[6,37] It has been hypothesized that the decreased dead space from smaller incisions and the muscle-splitting approach used in MISS creates less potential for formation of pseudomeningocele and persistent CSF leak in cases complicated by a durotomy.[37] Therefore, it is important to examine whether MISS results in lower rates of complications after a durotomy and whether any modifications need to be made in the perioperative management of durotomy in MISS cases.

In this report, we present our series of patients who underwent MISS with unintended durotomies and propose a management algorithm for this complication.

Abbreviation used in this paper: MISS = minimally invasive spine surgery.

Methods

All patients who underwent MISS performed by the senior author (J.E.O.) between August 2006 and February 2011 were identified from a prospectively collected database that includes all perioperative complications. Approval for the study was obtained from the Rush Uni-

versity Institutional Review Board. Patient demographics, preoperative records, operative notes, and postoperative records were reviewed. For the purposes of the case-control analysis, all patients with a durotomy were identified as cases and those without a durotomy were identified as controls. Variables included in the analysis were patient age, patient sex, history of previous surgery at the same level ("reoperation status"), fusion procedure, presence of synovial cyst at the operative level, spine region (cervical, thoracic, or lumbar), diagnostic category (degenerative, traumatic, neoplastic, infectious, congenital, or other), and size of retractor tube (16–18 mm, 20–22 mm, or 26 mm–expandable). Univariate chi-square and multiple logistic regression analyses were performed.

Surgical Technique

All cases were performed with tubular dilator systems (Medtronic Sofamor Danek and Globus Medical) under loupe or microscope magnification. Typically, an 18-mm-diameter tube was used for discectomies, a 20- to 22-mm tube was used for laminotomies, and a 22- to 26-mm tube was used for fusions. The technique for MISS decompression and fusion has been described in detail elsewhere.[17,22]

When a durotomy was recognized, the defect was covered by a small piece of Gelfoam (Johnson & Johnson) and cottonoid and definitively treated as described below, or alternatively the primary procedure was completed and the durotomy was subsequently addressed. Our treatment algorithm is presented in Fig. 1. All patients with only partial-thickness durotomies and intact arachnoid were treated with fibrin glue only. For full-thickness durotomies, the possibility of primary repair was assessed. For durotomies located at the edge or undersurface of the bony opening or the ventral surface of the dura, primary repair was often not possible. More dorsally or dorsolaterally located durotomies were typically suitable for primary repair, which was performed using interrupted 4-0 Nurolon sutures (Ethicon). In each case, a commercially available, specialized set of dural repair instruments was used that includes 2 modified needle drivers and a bayoneted Chitwood Knot Pusher (Scanlan International; Fig. 2). If the repair was not watertight to Valsalva maneuver, a small piece of locally harvested paraspinal muscle was sutured in as a buttress graft. In either case, the repair was followed with application of fibrin glue. For cases in which primary repair was not possible, a small blood-soaked piece of Gelfoam was laid over the dural defect (often gently tucked under the bony edge to secure it in place), followed by fibrin glue.

After allowing the fibrin glue to congeal, the tubular retractor was slowly removed, and meticulous hemostasis in paraspinal muscles was achieved with bipolar coagulation. Interrupted 0 Vicryl sutures were used to close fascia, and skin was closed with interrupted 2-0 Vicryl subcutaneous sutures followed by Dermabond (Ethicon). No lumbar or subfascial drains were used. The patients were kept on strict bedrest overnight and were allowed to fully mobilize on the morning of postoperative Day 1. No additional antibiotics were administered.



Fig. 1. Management algorithm for unintended durotomy in MISS.

Results

The cases of 563 consecutive patients were reviewed. Durotomies occurred in 53 patients for an overall unintended durotomy incidence of 9.4%. The demographics and operative details for the durotomy cases are presented in Table 1. Twenty-three patients were men (43%) and 30 patients were women (57%). The mean age at surgery was 60.7 years (range 30–85 years). Previous surgery at the same level was performed in 5 patients (9.4%). Two of the patients underwent posterior cervical surgery, and 51 patients underwent posterior lumbar surgery. Decompression (most commonly 1- or 2-level laminotomy for spinal stenosis) was performed in 32 patients (60.4%), and decompression with fusion was performed in 21 patients (39.6%). The mean operative time was 105 minutes in the decompression group and 310 minutes in the fusion group



Fig. 2. Dural repair instruments: curved needle holder **(upper)**, Jacobson needle holder **(center)**, and knot pusher **(lower)**. Printed with permission from Scanlan International.

($p < 0.001$). Estimated blood loss was 60 ml in the decompression group and 381 ml in the fusion group ($p < 0.001$). Length of stay was 2.2 days in the decompression group and 4.4 days in the fusion group ($p < 0.001$). In control patients without durotomies, the length of stay was 1.3 days in the decompression group ($p = 0.01$) and 4.0 days in the fusion group ($p = 0.69$). Follow-up data were available in 48 patients. The mean follow-up was 310 days (range 25–1208 days) overall: 182 days (range 25–917 days) in the decompression group and 489 days (range 95–1208 days) in the fusion group.

TABLE 1: Patient demographics and operative details in durotomy patients

Variable	Value
no. of patients	53
male	23 (43%)
female	30 (57%)
mean age at op (yrs)	60.7 (range 30–85)
previous op	5 (9.4%)
op type	
decompression	32 (60.4%)
fusion	21 (39.6%)
mean op time (minutes)	
decompression	105
fusion	310 ($p < 0.001$)
mean estimated blood loss (ml)	
decompression	60
fusion	381 ($p < 0.001$)
mean length of stay (days)	
decompression	2.2
fusion	4.4 ($p < 0.001$)
mean follow-up (days)	
decompression	182 (range 25–917)
fusion	489 (range 95–1208)
overall	310 (range 25–1208)

Risk Factors

Of the risk factors studies, the variables that achieved statistical significance on univariate chi-square analysis were previous surgery at the same level ($p = 0.019$) and location in the lumbar spine ($p = 0.001$). On multiple regression analysis (Table 2), location in the lumbar spine remained statistically significant ($p < 0.001$), while reoperation status showed a trend toward significance ($p = 0.088$).

Diagnosis and Repair

All durotomies were recognized intraoperatively. In 46 patients, egress of CSF was noted through a full-thickness dural opening, and in 7 patients arachnoid herniation through a partial-thickness dural defect was seen. Eight of the full-thickness dural violations were deemed appropriate for primary repair. Of these, one required a muscle buttress to achieve a watertight closure. All patients were maintained on bedrest until the morning after surgery (< 24 hours).

Complications

No patient developed a postoperative cutaneous CSF fistula or pseudomeningocele. No patient complained of persistent headaches or nausea. There were no new neurological deficits or any other complications attributable to durotomy after surgery. A superficial wound infection developed in 1 patient following a 1-level fusion that required a return to the operating room for irrigation and debridement, followed successfully by a short course of antibiotics. No evidence of subfascial infection or pseudomeningocele was identified in this patient at revision surgery.

Discussion

Unintended durotomy remains a frequent complica-

TABLE 2: Multiple logistic regression analysis for possible risk factors associated with durotomy

Variable	p Value
sex	0.785
age	0.194
reoperation status	0.088*
fusion procedure	0.953
presence of synovial cyst	0.144
region of spine op	<0.001*
diagnostic category	0.463
tube diameter	0.882
goodness of fit (Hosmer & Lemeshow)	1.000

* Statistically significant.

tion of spinal surgery, occurring in 1.6%–17.4% of cases.[1,4,11,12,19,21,30,31,35–40,42] In the largest series of consecutive lumbar decompression and/or fusion cases to date, Khan et al.[21] reported an overall durotomy incidence of 10.6%, with an increased incidence (15.9%) in the revision group. Our incidence of 9.4% is thus in line with previously reported numbers.

Multiple risk factors for durotomy have been previously reported, including older age, thin dura due to chronic compression, ossification of the ligamentum flavum, synovial cysts, scar from prior surgery, and surgeon inexperience.[3,4,10,12,21,33,41] In our case-control study, the only risk factors that were statistically significant were previous operation at the same level and lumbar spine region. Although reoperation status did not maintain significance in multiple regression analysis, this is most likely due to a small number of reoperations in our series and would likely reach significance with a larger sample size. The importance of lumbar spine region as a risk factor is unclear, as we had significantly more lumbar than cervical or thoracic cases, which could bias the results.

Primary repair of incidental durotomy is considered to have the highest rate of success,[3,11,15,19,36] although this is not always technically feasible due to thin dura or inaccessible location of the durotomy. This is particularly true in minimally invasive cases, in which a small tubular retractor may not allow the necessary manipulation of instruments to attain primary closure of the dura. In our series, the durotomy warranted primary closure in 8 patients; in all of these patients we were able to suture the dura using a specialized set of instruments designed for MISS dural repair. To our knowledge, there is only 1 other report of dural repair in MISS in which the authors successfully repaired a dural tear in a patient by using a standard pituitary rongeur and a laparoscopic knot pusher.[6]

Other methods described for repair of durotomies include using muscle or fat graft,[4,11,39] blood-soaked Gelfoam or Surgicel (Ethicon),[3,4,31,39] collagen matrix,[29] fibrin glue,[18,20,32] and metallic clips.[2,13] In our series, we used fibrin glue alone for partial-thickness durotomies, blood-soaked Gelfoam with fibrin glue for small full-thickness durotomies, and muscle graft or collagen matrix with fibrin glue to reinforce nonwatertight primary closure of larger durotomies. Using this strategy, summarized in Fig. 1, we were able to achieve a 0% incidence of CSF leaks or any other complications attributable to the durotomy.

Traditionally, a period of bedrest anywhere from 1 to 7 days has been recommended after a durotomy occurs during open spinal surgery.[4,11,16,21,39] In the only study of durotomy after MISS procedures,[37] the authors evaluated 5 patients with unintended durotomies and recommended mobilization within 48 hours of surgery. In our series, all patients were mobilized less than 24 hours postoperatively without any complications, suggesting that MISS may allow for faster mobilization after a durotomy than open spine surgery.

Although the length of stay was longer for patients with a durotomy undergoing decompressive procedures, no such difference was found in patients undergoing fusion procedures. The likely explanation is that—in absence of durotomy—a high proportion of patients undergoing decompressive procedures were discharged on the day of surgery, whereas durotomy patients were kept on bedrest overnight, thus prolonging the average length of stay. Durotomy did not increase the length of stay in fusion patients, likely due to our early mobilization protocol, which enabled the patients to meet usual discharge criteria.

The use of drains after unintended durotomy has been controversial. Despite the classic teaching that drains may increase the risk of cutaneous CSF fistula formation,[3,11] several authors have described the routine use of subfascial drains after primary repair of durotomies without increased incidence of fistulas or other complications.[4,21,39] Lumbar subarachnoid drains have also been used, primarily in the management of postoperative CSF leak and pseudomeningocele.[11,19,23,34] We do not routinely use drains for MISS cases, and thus no subfascial or lumbar drains were placed in any of the patients in this series. We believe that one of the benefits of MISS in the setting of durotomy is the decreased dead space resulting from a smaller incision and muscle-splitting approach. Compared with the open approach, this decreases the potential space for CSF accumulation and formation of pseudomeningocele, thus obviating the need for a drain.

Most previously published studies have reported few long-term consequences after unintended durotomy.[4,8,9,19,39] However, serious complications, such as neurological deficit, pseudomeningocele, meningitis, and intracranial hemorrhage, have been reported.[4,5,7,11,14,20,23–28,34,42] In addition, rates of persistent CSF wound leak and pseudomeningocele formation have been reported to be as high as 17.6%.[15] In our series of patients with a mean follow-up of 310 days, there were no complications referable to durotomy, which compares favorably with the current literature on durotomies after open cases.

The limitations of this study are small sample size and lack of either an open spinal surgery control group or comparison with disparate durotomy repair strategies. A large randomized trial comparing open to minimally invasive surgery would be necessary to confirm or refute our findings of decreased complications in the MISS durotomy group. In addition, longer follow-up may be necessary to elucidate whether durotomy impacts long-term clinical outcome in patients after MISS procedures. Finally, the algorithm that we suggest here may have several other viable alternatives that we did not use but that could result in equally good outcomes.

Conclusions

We report here the most comprehensive review of unintended durotomy incidence and management during MISS. In our consecutive series of patients undergoing MISS, we found that an unintended durotomy was associated with fewer complications than previously reported for open spinal surgery. Our case-control study using multiple logistic regression analysis revealed lumbar spine region and possibly reoperation status as risk factors for durotomy. We propose a simple management algorithm for durotomy repair that includes early mobili-

zation and results in excellent clinical outcomes with no incidence of postoperative cutaneous CSF fistula or other complications.

Disclosure

Dr. O'Toole is a consultant for Globus Medical, Inc.

Author contributions to the study and manuscript preparation include the following. Conception and design: both authors. Acquisition of data: both authors. Analysis and interpretation of data: both authors. Drafting the article: Ruban. Critically revising the article: O'Toole. Statistical analysis: both authors.

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Manuscript submitted June 7, 2011.
Accepted July 21, 2011.

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Neurosurg Focus 31 (4):E16, 2011

Abdominal complications following posterior spinal fusion in patients with previous abdominal surgeries

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Perioperative abdominal complications associated with spine surgery are rare. Although most known abdominal complications occur in conjunction with anterior spinal fusions, there is a paucity of reports reviewing abdominal complications occurring with posterior spinal fusions. The authors review 4 patients who experienced a perioperative abdominal complication following a posterior spinal fusion. In each of these patients, a history of abdominal surgery is present. Given the physiological changes that occur with surgery in the prone position, patients with previous abdominal surgeries are at risk for developing abdominal complications in the perioperative period.
(DOI: 10.3171/2011.8.FOCUS11132)

Key Words • **posterior spinal fusion** • **abdominal complication** • **abdominal compartment syndrome** • **hernia**

Spine surgery is associated with perioperative morbidity and mortality in the adult population.[17,19] Poor outcomes can be related to abundant blood loss associated with large fusions or advanced patient age.[3,8,31] An understanding of relevant risk factors is important in minimizing morbidity and mortality. Although abdominal complications are uncommon in spine surgery, they have been reported to occur in patients with anterior spinal fusion.[15,22,23,25] Furthermore, spinal manipulation for the correction of scoliotic deformity can lead to superior mesenteric artery syndrome when the superior mesenteric artery places compression on the duodenum.[1,9,12,24] Recently, abdominal complications, in particular ACS, have been described in patients with posterior spinal fusions.[27] The authors present a series of patients with a history of abdominal surgery who experienced an abdominal complication following a posterior spinal fusion.

Methods

The authors conducted a retrospective review of a series of posterior spinal fusions performed in the Department of Neurological Surgery at Northwestern Memorial Hospital between September 2009 and August 2010. Approval to conduct the study was obtained from the institutional review board prior to its initiation. During this period, a chart review was performed in all patients with prior abdominal surgery who had undergone a posterior spinal fusion and suffered an abdominal complication requiring intervention during the perioperative period. For each patient, the BMI and the number and nature of prior abdominal surgeries are documented. The description of the spine procedure, time of surgery, estimated blood loss, urine output, intraoperative fluid given, abnormal results of intraoperative laboratory tests, and the amount of required transfusion is recorded. For any patient with an abdominal complication, the length of time between the date of the operation and the date of the diagnosis of complication, the nature of the injury, and any surgical intervention are noted.

Abbreviations used in this paper: ACS = abdominal compartment syndrome; BMI = body mass index; IAP = intraabdominal pressure.

Results

One hundred sixty-six patients were found to have undergone a posterior lumbar fusion between September 2009 and August 2010. In this group, 55 patients had undergone a previous abdominal surgery, and 4 of these 55 patients (7.2%) had an abdominal complication in the perioperative period following their spine surgery. There were 111 patients with no history of abdominal surgery. No patients in this group had a related abdominal complication.

Case Reports

Case 1

History and Examination. This patient was a 79-year-old morbidly obese (BMI 44) woman with a medical history significant for hypertension, elevated cholesterol, obstructive sleep apnea, and gastroesophageal reflux disease. She had an extensive surgical history that included a cholecystectomy and exploratory laparotomy for a colon perforation many years previously. She had also undergone a left L5–S1 minimally invasive foraminotomy in 2007 for a unilateral radiculopathy. The patient presented to clinic several years later with progressive low-back pain as well as neurogenic claudication. Multiple modalities of nonoperative management had failed in this patient.

Operation. The patient ultimately consented to and underwent an L4–5 transforaminal lumbar interbody fusion. Pertinent operative details include positioning on an open Jackson table. Given her morbid obesity, there was some difficulty in containing the patient's abdomen with the Jackson table. The procedure itself was unremarkable, with a total estimated blood loss of 50 ml, and the operating time was 165 minutes. She did not require a transfusion intraoperatively and there were no abnormal laboratory values in the perioperative period. The patient received 2 L of crystalloid and 500 ml of hextan during the operation. No Foley catheter was placed for the operation and no urine output was recorded. The patient was extubated in the operating theater and transferred to the postanesthesia care unit. Her neurological examination was unchanged from her preoperative status.

Postoperative Course. Once she was stable, the patient was transferred to the general neurosurgical floor. On the 1st postoperative day the patient worked with the physical and occupational therapists and began to ambulate. An anteroposterior and lateral lumbar spine x-ray study obtained on the 1st postoperative day revealed acceptable positioning of the interbody cage and posterior instrumentation. On the 3rd postoperative day the patient began to experience increased nausea, with 2 episodes of emesis. She had already had a small bowel movement. An abdominal film did reveal findings of a partial small-bowel obstruction secondary to a right inguinal hernia. Due to progressive nausea and vomiting, the patient had a nasogastric tube placed later that evening. The general surgery service was also consulted. She exhibited minimal tenderness to palpation, but no guarding or peritonitis. The patient's clinical status improved with nasogastric drainage. A CT scan of the abdomen and pelvis revealed transition points in the vicinity of the fascial defect of abdominal wall (Fig. 1). There was no free air. By the afternoon of postoperative Day 4, the patient's status deteriorated and she began to demonstrate signs of peritonitis. On the 4th postoperative day, the patient was taken to the operating room by general surgery for an exploratory laparotomy and reduction of 5 different incarcerated hernias. The patient experienced a prolonged hospital course, which included 2 weeks in the surgical intensive care unit. Her open abdominal wound was eventually partially closed with a vicryl mesh and negative pressure wound therapy. She was ultimately discharged to a skilled nursing facility on postoperative Day 31.



Fig. 1. Case 1. Sagittal CT scan of the abdomen and pelvis showing an abdominal wall fascial defect leading to an incarcerated hernia producing small-bowel obstruction.

Case 2

History and Examination. This patient was a 61-year-old morbidly obese (BMI 51) woman with a medical history significant for hypertension, hypothyroidism, pulmonary embolus on warfarin, chronic renal failure on dialysis, and a remote history of bacterial peritonitis due to mesenteric ischemia in 1992. At that time she underwent partial colectomy and temporary ostomy placement. This course was complicated by *Candida* osteomyelitis, for which the patient underwent 2 prior thoracolumbar operations (T4–L3 posterior instrumentation and fusion). She was evaluated in the outpatient setting for many years for progressive low-back pain and neurogenic claudication. Ultimately, she consented to and underwent an L3–4 laminectomy and revision of her prior fusion at L-1 and extension to S-1 and the ilium. She also had an inferior vena cava filter placed at the time of this operation.

Operation and Postoperative Course. The duration of her operation was 630 minutes. During the case, the patient received 2.7 L of crystalloid, 4.5 L of colloid, 5 U of packed red blood cells, 3 U of platelets, and 1 U of cryoprecipitate. The estimated blood loss was 2.7 L, and urine output was 570 ml. The only abnormal immediate postoperative value was a hemoglobin level of 11.3 g/dl. On postoperative

Day 5 the patient experienced increasing epigastric pain, and an abdominal x-ray showed a large dilated loop of colon in the midabdomen. The general surgery service was consulted and an abdomen/pelvis CT scan was obtained, which showed a nonobstructive pattern of gas and findings consistent with an ileus. A nasogastric tube was placed and she improved clinically. However, in the early afternoon of postoperative Day 6, the patient exhibited signs and symptoms of peritonitis. She was taken to the operating room by the general surgery service for an exploratory laparotomy, lysis of adhesions, small-bowel resection, and repair of perforation in the distal small bowel. She subsequently underwent multiple explorations and anastomotic repairs. She developed *Enterobacter cloacae* sepsis and eventually had acute renal failure. After a prolonged hospitalization the patient recovered, with the exception of her renal failure. The patient elected to discontinue dialysis and entered hospice care.

Case 3

History and Examination. This patient was a 60-year-old man (BMI 24) with history of multiple medical problems, including renal cell carcinoma, ulcerative colitis, and chronic lower-extremity deep venous thrombosis. Surgical history was significant for right-sided nephrectomy and inferior vena cava filter insertion. Regarding his renal cell cancer, the patient had been diagnosed 10 years prior to presentation at our institution. Several years after the initial diagnosis, he was found to have a sacral metastatic lesion that was treated with radiation and immunotherapy. Years later this recurred, and he was again treated with radiation and immunotherapy. The patient did well for a period of time until he developed progressive low-back pain and was found to have necrosis of L-5. Before presenting to our institution, he underwent an anterior approach for corpectomy, which was aborted due to extensive scarring and resulted in posterior instrumentation being placed. His postoperative course was complicated by a methicillin-resistant wound infection, which resulted in numerous surgical interventions to repair the instrumentation and wound. He then developed wound dehiscence, and a diagnosis of recurrent methicillin-resistant *Staphylococcus aureus* infection was made; the patient underwent instrumentation removal and transferred to our institution for definitive surgical management.

Operation. Once he was admitted to our institution, the patient's care was co-managed by several services, including the general medicine, infectious disease, and gastroenterology services. He eventually underwent 2 different surgeries as part of a larger surgical plan. The first stage was an exploration of his prior thoracolumbar wound and removal of his remaining instrumentation. This operation lasted 100 minutes. The estimated blood loss from this operation was 50 ml, and the urine output was 300 ml. No transfusions were given. Additionally, the patient received 1.5 L of crystalloid and 500 ml of hetastarch solution.

He recovered from the first stage without issues, and 1 week later was brought back to the operating room for the second stage of the procedure. The second stage consisted of a posterior instrumentation and fusion from L-2 through S-1 with iliac screw placement. The operation included a transiliac bar and a 4-rod lumbosacral construct. The L-5 pathological condition was addressed with a right partial L-5 pediculectomy, revision of the prior L-5 corpectomy, and irrigation and debridement of osteomyelitis. Additionally, a custom-cut titanium cage was inserted into the L5–S1 disc space to achieve stability and serve as a site for fusion. The wound was closed by our plastic surgery colleagues by using 2 different flaps, as follows: 1) a superior gluteal artery pedicled flap for the midline; and 2) a latissimus dorsi V-Y myocutaneous flap. This operation lasted 626 minutes. Intraoperatively, the patient received 5 L of colloid, 2 L of crystalloid, and 8 U of packed red blood cells. The estimated blood loss was 2.8 L. Urine output was 2.9 L.

Postoperative Course. Following the operation, he had an uneventful hospitalization and was discharged to a rehabilitation facility on postoperative Days 17 and 24. On postoperative Days 22 and 29, the patient was brought to our institution's emergency department with progressive abdominal pain. He was evaluated by the general surgery service and a CT scan showed a small-bowel obstruction with an incarcerated hernia (Fig. 2). The patient was taken to the operating room for emergency exploratory laparotomy and reduction of the incarcerated hernia. He had an uneventful recovery and was transferred back to his original rehabilitation facility on postoperative Day 6 after the laparotomy.

Case 4

History and Examination. This 48-year-old obese (BMI 30) woman had a medical history of mitral valve prolapse, obstructive sleep apnea, and irritable bowel syndrome. Her surgical history included 4 different ventral hernia repairs and adolescent scoliosis correction with Harrington rods. The patient was evaluated in the out-

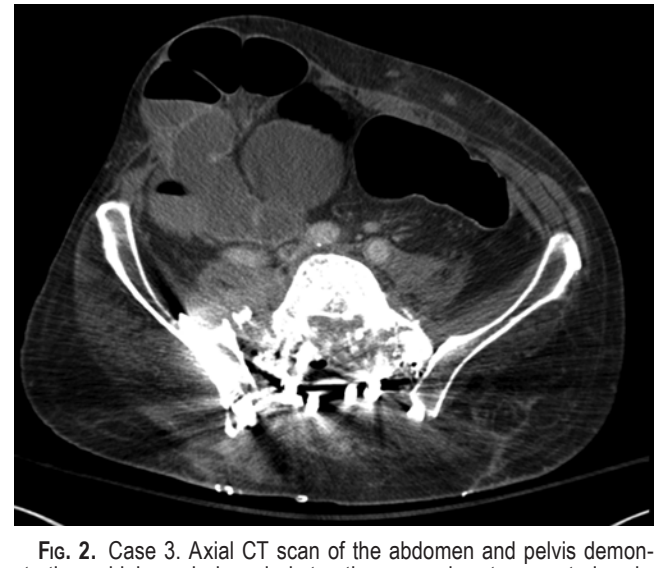


Fig. 2. Case 3. Axial CT scan of the abdomen and pelvis demonstrating a high-grade bowel obstruction secondary to an anterior abdominal wall hernia containing small bowel.

patient setting and it was recommended that she undergo correction of her progressive kyphoscoliosis.

Operation and Outcome. Due to her medical comorbidities and nature of the planned surgical interventions, the patient had an inferior vena cava filter placed during the first surgery. The patient had been under general anesthesia and in the prone position for approximately 10 hours when she experienced frank disseminated intravascular coagulation. At this point in the case, all instrumentation had been placed and the surgeon had just completed a pedicle subtraction osteotomy and final rod placement. At that time, her cumulative total blood loss was 6000 ml and she had received 2000 ml of crystalloid, 1900 ml of red blood cells from the cell saver, 3000 ml of 5% albumin, 11 U of packed red blood cells, 3 U of platelets, and 4 doses of pooled cryoprecipitate. Her hemoglobin was 13.0 g/dl, she had a platelet count of 115,000, international normalized ratio 1.4, fibrinogen 239 mg/dl, and her arterial blood gas had a pH of 7.41, PCO_2 of 31, PO_2 of 205, and a base deficit of −4. While the closing staples were being placed, the patient developed a junctional bradyarrhythmia with an arterial line systolic blood pressure of 98, diastolic blood pressure of 88, and mean arterial pressure of 90 mm Hg; she subsequently developed pulseless electrical activity. She was emergently returned to the supine position. It was clear that her abdomen was tense and distended. A bladder pressure was transduced via the Foley catheter that was noted to be approximately 100 mm Hg. A decision was made to proceed with emergency exploratory laparotomy for presumed ACS. Despite opening the abdomen, there was no improvement in her circulation or rhythm. In addition, there were no sites of massive hematoma in the intraperitoneal or extraperitonal spaces. The entire bowel was dusky and ischemic in appearance. Because of the futility of further efforts to resuscitate the patient, she was pronounced dead. The presumptive cause of death was ACS.

Discussion

Abdominal compartment syndrome is a potential complication occurring in high-risk spine surgery cases involving multilevel thoracolumbar fusion. These patients are at risk because of mechanical ventilation, fluid resuscitation, acidosis, coagulopathy, and polytransfusion.[6] A history of abdominal surgery places these patients at additional risk for developing ACS.[4] Tight abdominal closures can alter the compliance of the abdomen. Physiological changes that occur in the prone position are believed to contribute to abdominal complications.[13] In the prone position, visceral compression further contributes to alterations of wall compliance.[4] Abnormal values of IAP (> 12 mm Hg) can raise concern for the development of ACS. Initial management of intraabdominal hypertension should be focused on correcting any positive fluid balance. Maintaining abdominal perfusion pressure > 60 mm Hg is favored to prevent multiorgan failure.[5] Abdominal decompression is reserved for intraabdominal hypertension refractory to medical therapy.

Any signs suggesting multiorgan failure during an operation should raise concern of a possible ACS. A drop in systolic or diastolic blood pressure, a rise in PCO_2, a drop in O_2 saturation and PO_2, and a drop in urine output have all been shown to correlate with increased IAP.[21] Laboratory tests should be obtained periodically for any indication of coagulopathy or abnormal base deficit. Fluid balance should be strictly monitored. If there is evidence of abnormal laboratory test values, a decision should be made to stage the procedures. If high blood loss is suspected in a patient undergoing multilevel fusion who has had previous abdominal surgeries, is obese, and whose age is advanced, an intravesicular transducer should be considered to monitor IAPs during the procedure. Emergency surgical decompression is warranted and can be immediately life saving if the suspicion for ACS is high.[11] Delay in surgery has been shown to have bad outcomes.[18,21,29]

Small-bowel obstruction related to a physical impingement of the small bowel is not a known, documented complication of prone positioning. However, there are several factors that are believed to contribute to small-bowel obstruction in the setting of prone positioning used in posterior spinal fusion. Correlations have been seen between elevated IAP and prone position with spine surgery.[7,14,20] Three of 4 patients experiencing abdominal complications in this series were obese. With obese patients, the IAP is elevated compared with those with a normal BMI.[16,28,30] The risk of incisional hernia is also higher in obese patients.[26] Thus, these considerations must be factored into the preoperative assessment of patients with previous abdominal surgery who are at risk for incisional hernia and subsequent small-bowel obstruction.

For obese patients, a Jackson table can be used to provide less pressure on the abdomen by allowing it to hang free. However, there is a theoretical risk of increased IAP caused by fluid extravasation from the gravitational and hydrostatic pressures in the dependent area of the abdomen with obese patients. External abdominal support is not recommended because it can cause changes in compliance of the abdomen. Pressure points should be checked to insure that there is no focal impingement in any portion of the abdomen. For patients with known inguinal hernia and advanced age, abdominal hernias leading to emergency operations are associated with significant rates of morbidity and mortality.[2,10]

As these cases demonstrate, special consideration should be given to details of the placement in the prone position to prevent the development of an incarcerated or strangulated hernia. There should be a high suspicion for small-bowel obstruction in the postoperative period in any patient with increasing abdominal pain, worsening nausea and vomiting, or the absence of flatus and bowel movements. Physical examination assessing for a distended, rigid abdomen or evidence of an irreducible hernia should prompt workup with radiography and/or CT scanning of the abdomen and pelvis. Elevated lactic acid can occur with mesenteric ischemia and can be a reliable marker for early bowel ischemia. If signs and symptoms are suggestive of small-bowel obstruction, a nasogastric tube should be placed to provide decompres-

sion of the gastric contents. As these cases demonstrate, once bowel ischemia is present, the condition can be fatal or lead to a permanent disability and a prolonged hospitalization. Thus, in the setting of multiple risk factors, patients undergoing posterior spine surgery should be carefully monitored for the potential risk of developing small-bowel obstruction.

There are select cases in which patients who demonstrate a hernia or who have a history of hernia repair warrant a general surgery consultation prior to the procedure. These cases include any surgery in which there is an anticipated need for blood transfusions, the patient is obese, or the hernia is irreducible. Treating the hernia prior to surgery can prevent an unwanted abdominal complication.

Conclusions

Complications of spinal fusions are associated with the nature of the operation and predisposing risk factors. Despite the low incidence, there can be some significant abdominal complications occurring in patients with previous abdominal surgeries who elect to undergo posterior spinal fusions. The physiological changes that occur during operation in these cases can escalate this risk of surgery. The key to preventing a complication in these situations is awareness and early intervention.

Disclosure

Support for a nonstudy-related clinical or research effort overseen by Dr. Fessler was received from Medtronic, Inc. 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: Koski. Acquisition of data: Shih, Slimack, Roy. Drafting the article: Koski, Shih, Slimack. Critically revising the article: Koski, Shih, Slimack, Fessler. Reviewed submitted version of manuscript: Shih, Slimack. Approved the final version of the manuscript on behalf of all authors: Shih. Study supervision: Koski, Fessler.

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Manuscript submitted June 13, 2011.
Accepted August 2, 2011.

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Neurosurg Focus 31 (4):E17, 2011

Revision strategies for AxiaLIF

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Object. Paracoccygeal transsacral fixation is a novel percutaneous technique for arthrodesis of L5–S1 and L4–5 (Axial Lumbar Interbody Fusion [AxiaLIF]). There are no reports on feasible revision strategies. The goal of this paper is to analyze the surgical details of failed AxiaLIF constructs and to describe revision strategies.

Methods. The medical charts, operative records, and imaging studies of 5 patients with failed multisegment instrumentation using the AxiaLIF device were reviewed.

Results. AxiaLIF constructs were revised in 5 patients with a mean age of 58.4 years. All AxiaLIF devices were part of multisegment fusion constructs for revision surgery and were revised an average of 15 months after implantation. Two AxiaLIF devices were percutaneously retrieved; one because of excessive bone resorption around the AxiaLIF screw, and the other because of chronic hardware infection. In these 2 patients, the anterior column was subsequently stabilized via anterior lumbar interbody fusion. In the other 3 patients, the AxiaLIF device was left in situ. In 2 of these patients the anterior column was stabilized with bilateral L5–S1 posterior lumbar interbody fusion, and in the remaining patient with L4–5 instability the posterior instrumentation only was revised. Revision surgeries were well tolerated. One patient suffered from a wound dehiscence of the back wound.

Conclusions. AxiaLIF devices are safely retrieved using percutaneous technique. Both anterior and posterior revision strategies may be used to achieve anterior column fixation. *(DOI: 10.3171/2011.8.FOCUS11139)*

Key Words • AxiaLIF • lumbar interbody fusion • pseudarthrosis • minimally invasive spine surgery • revision • complication

Percutaneous paracoccygeal transsacral fixation (AxiaLIF, Trans1, Inc.) has become an increasingly popular method for instrumentation of the lower lumbar spine.[4,8,9] The AxiaLIF procedure allows for straightforward access to L4–5 and L5–S1 via the presacral space. Therefore, it eliminates muscle detachment, ligamentous disruption, and incision of the anulus, and it minimizes destabilization of the joint.[1,13] Biomechanical studies have proposed that the AxiaLIF device in combination with posterior fixation offers stability similar to anterior interbody fusion cages augmented with a posterior construct.[2,5] The AxiaLIF procedure has been reported to be associated with a low risk of complications such as visceral, vascular, or sympathetic injury.[4,15] The rate of immediate operative complications of the first 5000 1- and 2-level AxiaLIF procedures was 1.08% (unpublished data).

Known complications of spinal fusion surgery include bony nonunion and instrumentation failure and require revision surgery in 6%–36% of cases.[6] Revision surgeries tend to be associated with a poorer functional outcome than initial surgeries, and they also have a higher complication rate.[7,10] A recent study reported that ALIF lumbar spine fusions may be revised using either anterior or combined anterior-posterior procedures.[11] However, while the authors found that revision surgery was generally performed safely following ALIF procedures, they noted a high rate of early complications (44%). Likewise, revision of TLIFs has been described using posterior,[3] anterior, and combined approaches.[16] Given its recent introduction, there is a lack of published literature on issues relating to revision strategies of failed AxiaLIF instrumentation. Additionally, given the unique access corridor, there is a need for a detailed technical description of removal and revision of the AxiaLIF constructs.

Abbreviations used in this paper: ALIF = anterior lumbar interbody fusion; AxiaLIF = Axial Lumbar Interbody Fusion; BMP = bone morphogenetic protein; PEEK = polyetheretherketone; PLIF = posterior lumbar interbody fusion; TLIF = transforaminal lumbar interbody fusion.

In this report, we present the surgical technique for percutaneous removal of the AxiaLIF device and present several revision strategies for revision AxiaLIF surgery.

Methods

Patient Population

Our institutional database was searched to retrieve all patients who had undergone revision surgery involving AxiaLIF devices since 2006. The medical charts, radiological records, and operative reports of 5 patients were reviewed. All initial AxiaLIF surgeries were performed at our institution between January 2008 and November 2009. Basic epidemiological data such as age, sex, and indication for the initial AxiaLIF placement were recorded. Operative reports were reviewed for operative times, estimated blood loss, and type of instrumentation. The length of hospital stay and postoperative complications were recorded. This study was approved by the institutional review board, and written informed consent was obtained from all patients prior to inclusion in the current study.

Surgical Procedure

Initial AxiaLIF procedures were performed according to standard protocol.[4,12,15] Silicate-substituted calcium phosphate (Actifuse, Baxter) was used as bone graft. No BMP was used during the index AxiaLIF insertion. Preoperative planning for AxiaLIF removal included pelvic MR imaging to identify possible space-occupying lesions (such as seromas and abscesses), to assess the width of the presacral space, and to look for obvious postoperative adhesions. A CT scan was also obtained to determine bone formation and overgrowth at the AxiaLIF screw head. Consistent with the implantation surgery, all patients were recommended to undergo a full mechanical bowel preparation prior the procedure.

Surgical Removal of the AxiaLIF Device

AxiaLIF removal was performed in 2 of 5 patients. Patient positioning for removal of the AxiaLIF device is identical to positioning for implantation. The original skin incision is reopened, and the pelvic floor muscles are perforated in a blunt fashion using a closed clamp, with care taken to enter the presacral space and develop a working corridor using digital dissection. Under fluoroscopic guidance, a blunt guide pin is advanced while maintaining contact with the presacral fascia covering the sacrum and is carefully advanced (Fig. 1A and B). With bone overgrowth, metal-to-metal contact may not be appreciated when the guide reaches the screw head of the AxiaLIF implant. Once the tip of the blunt guide is precisely centered on the screw head of the AxiaLIF device on anteroposterior and lateral imaging, a 1-level guidewire (3.2 mm in diameter) is impacted into the core of the AxiaLIF device using a mallet (Fig. 1C). After confirmation of the correct insertion of the guidewire, the blunt guide is withdrawn, leaving the guidewire in place. Following a series of blunt dilators, a beveled exchange cannula is brought in place as a working channel (Fig.

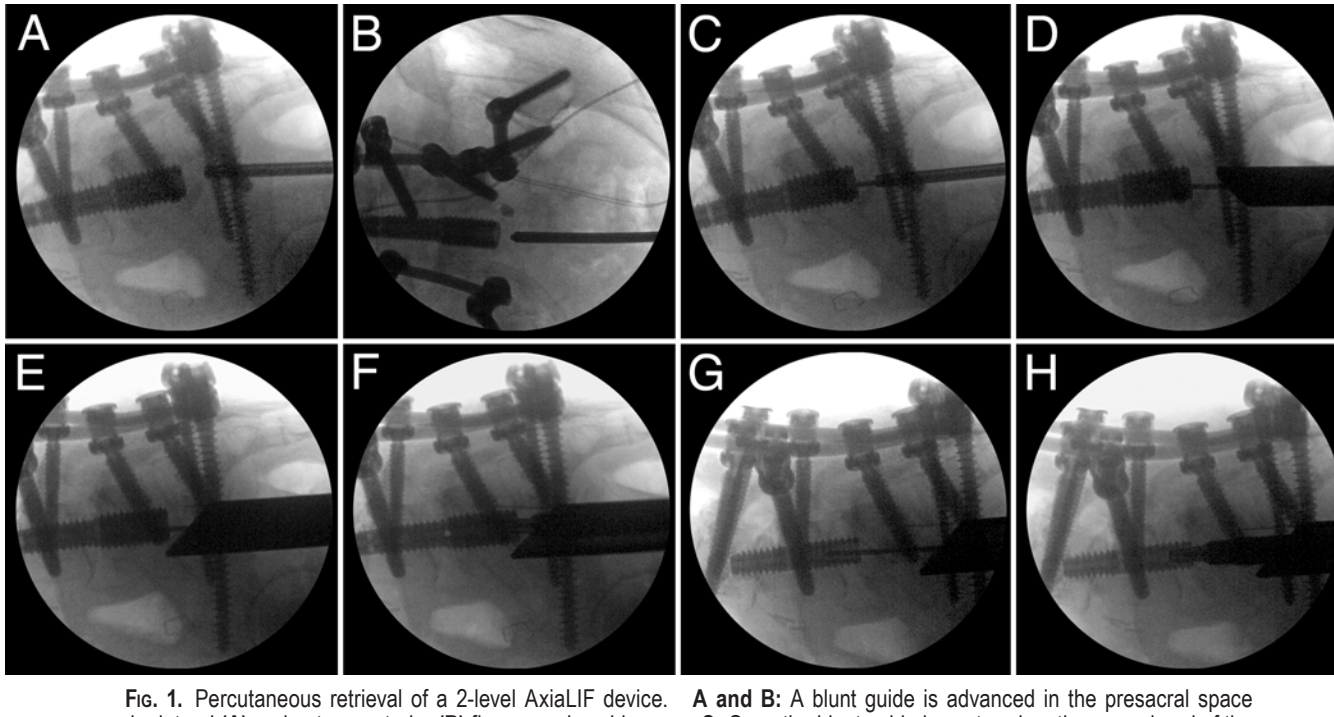


Fig. 1. Percutaneous retrieval of a 2-level AxiaLIF device. **A and B:** A blunt guide is advanced in the presacral space under lateral **(A)** and anteroposterior **(B)** fluoroscopic guidance. **C:** Once the blunt guide is centered on the screw head of the implant, a guidewire is advanced into the core of the implant. **D and E:** A series of dilators are advanced over the guide pin. Note that during insertion the leading edge of the beveled cannula is oriented dorsally to minimize risk of visceral damage **(D)**. The exchange cannula is anchored to the sacrum with a fixation wire (1.4 mm in diameter; **E**). **F:** Using the AxiaLIF Retrieval Expanding Hex Sub-Assembly, the proximal rod is removed. **G:** The guidewire is advanced to the distal rod. **H:** The distal rod is removed.

1D and E) and is anchored to the sacrum by using a fixation wire (1.4 mm in diameter). The manufacturer offers 2 main tools for rod extraction: the AxiaLIF Extraction Tool and the Retrieval Expanding Hex Sub-Assembly. The extraction tool is designed to engage the mating threads; however, in our experience this was hampered by local bone ingrowth as well as by suboptimal alignment of the extraction tool and the AxiaLIF device. The expanding hex device is advanced using a mallet and is expanded once in place; in our experience, this tool allowed for secure and efficient removal. Primary attempts at extraction may be best undertaken using the extraction tool as subsequent utilization of the expanding device may deform the screw threading. Prior to closure of the wound, the working corridor and adjacent bowel segments were inspected using a 30°-angled endoscope for possible bowel lacerations.

Statistical Analysis

Continuous variables are shown as means and ranges. All analyses were performed using appropriate statistical software (SPSS version 19.0.0.1, IBM SPSS).

Results

Revisions of AxiaLIF constructs were performed in 5 patients with a mean age of 58.4 years (range 38–73 years). All patients had undergone lumbar spine surgery prior to the AxiaLIF procedure. Moreover, the transsacral rod was part of multisegment constructs in all 5 patients (Table 1). In general, failure of instrumentation presented with exacerbation of low-back pain and radiolucency surrounding the transsacral rod on CT imaging. Revision surgery was performed 15 months (range 6–36 months) after the initial AxiaLIF procedure. In 2 patients the AxiaLIF device was removed, which required an average of 106 minutes (92 and 120 minutes) to perform. Revision of the anterior and posterior instrumentation required on average 511 minutes (range 342–870 minutes) and was associated with 820 ml (range 500–1500 ml) of blood loss. In 2 patients, the AxiaLIF device was removed, and anterior column support was achieved by ALIF. Removal of the device was necessary in 1 patient because of excessive resorption of bone surrounding the axial rod. The anterior approach allowed for placement of a wide spacer extending beyond the bony defect created by the AxiaLIF device and thereby decreasing abnormal postoperative stress distribution between the cage and vertebral endplate. In the other patient, the AxiaLIF device was removed in the setting of chronic hardware infections. In 3 patients, the arthrodesis was revised with the AxiaLIF device left in place. In 2 patients additional stabilization of the anterior column was achieved by bilateral PLIF surgery using expandable PEEK spacers. In the third patient the fusion construct was reinforced by revision of the posterolateral instrumentation. Intervertebral cages were filled with silicate-substituted calcium phosphate (Actifuse) supplemented with BMP. Patients tolerated revision surgeries well and left the hospital after an average of 8 days (range 5–14 days). One patient developed a wound dehiscence that required surgical washout and revision.

Case Reports

Case 1

This 38-year-old woman with a history of an L5–S1 discectomy presented with severe chronic low-back pain that was unresponsive to conservative treatment (Fig. 2A). Initial surgery with placement of an L5–S1 AxiaLIF and an L4–5 TLIF supplemented with unilateral pedicle screws was undertaken (Fig. 2B). The patient experienced partial relief of her low-back pain immediately following the procedure. Approximately 6 months after the procedure, the patient was the victim of a car accident and suffered from severe left lower-extremity pain. Imaging revealed loss of L5–S1 intervertebral disc height and S-1 superior endplate fracture (Fig. 2C and D). The patient underwent revision surgery with bilateral L5–S1 PLIF with placement of PEEK spacers filled with BMP and Actifuse. The posterolateral pedicle-rod constructs were revised and extended to the iliac crests using 3D navigation (Fig. 2E and F). The patient is now 3 years out from her revision surgery and experiences residual back pain. The construct has remained stable.

Case 2

This 66-year-old woman with a history of spine fusion

TABLE 1: Characteristics in 5 patients undergoing revision of AxiaLIF*

Age (yrs), Sex	Initial Pathology	AxiaLIF Level	Total Fusion Construct Levels	AxiaLIF Removed	Revision Strategy
38, F	DDD	L5–S1	L4–S1	no	bilat PLIF w/ PEEK spacer, extension of bilat posterolat instrumentation to iliac crest
66, F	adjacent-level disease	L4–S1	T5–S1	yes	ALIF L4–5 & L5–S1, extension of posterolat instrumentation to iliac crest
67, F	pseudarthrosis	L4–S1	L2–S2	yes	ALIF L4–5 & L5–S1, extension of posterolat instrumentation to L-1 & iliac crest
48, M	postlaminectomy syndrome	L4–S1	L3–S1	no	revision of posterolat instrumentation
73, M	pseudarthrosis	L5–S1	L2–S1	no	bilat PLIF w/ expandable PEEK cages, extension of posterolat instrumentation to iliac crest

* All patients underwent AxiaLIF procedures after previous spine surgery. Abbreviation: DDD = degenerative disc disease.

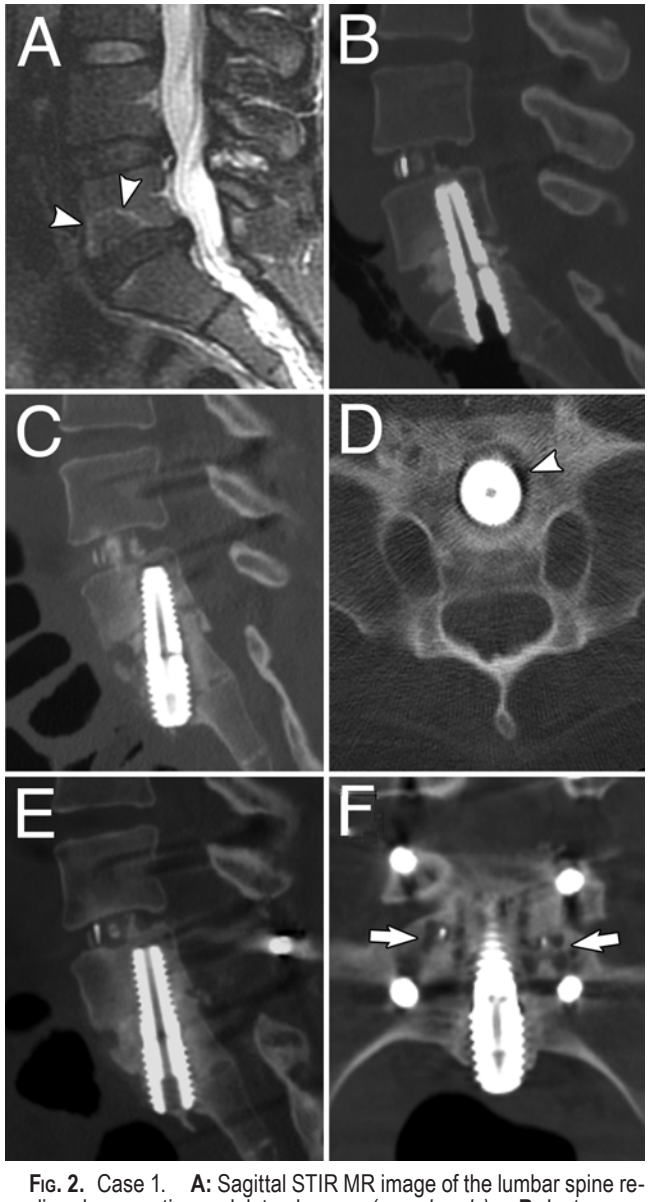


Fig. 2. Case 1. **A:** Sagittal STIR MR image of the lumbar spine revealing degenerative endplate changes *(arrowheads)*. **B:** Instrumentation of L5–S1 using AxiaLIF and of L4–5 by TLIF. **C and D:** After a car accident, the L5–S1 intervertebral space is collapsed and the superior endplate of S-1 is fractured. *Arrowhead* indicates radiolucency surrounding the rod in the vertebral body of S-1. **E and F:** Revision of the L5–S1 fusion with bilateral PLIFs *(arrows)* results in body fusion.

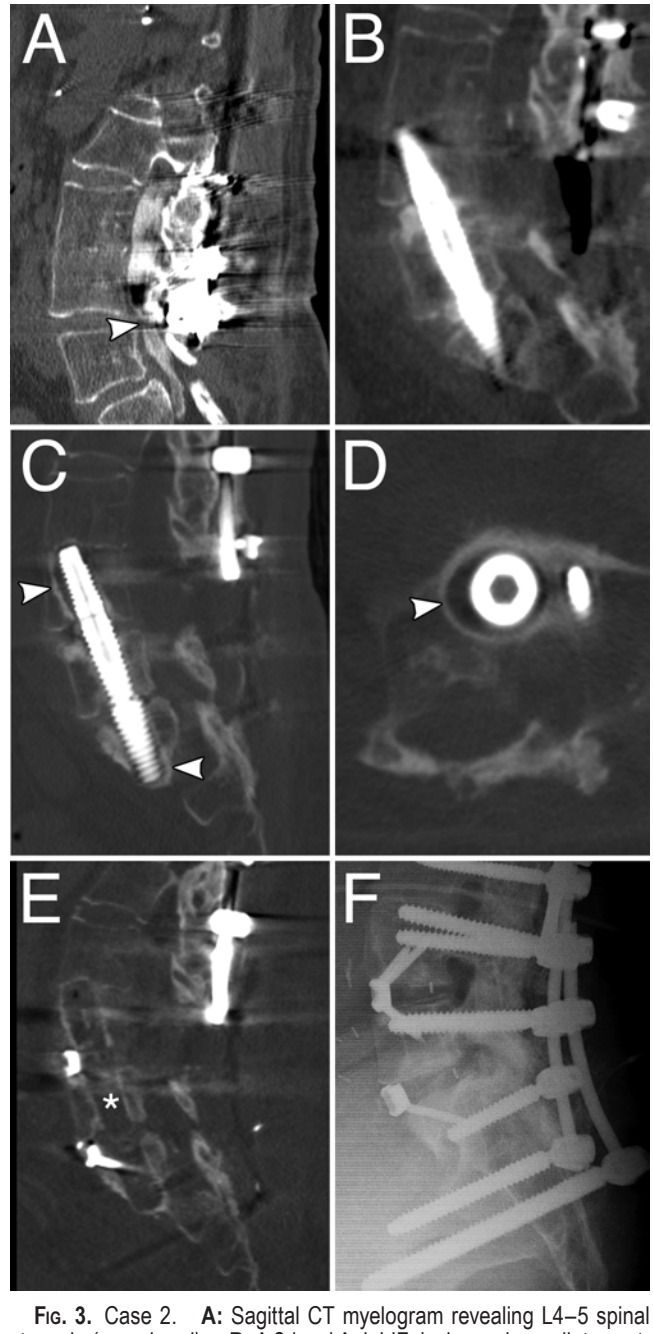


Fig. 3. Case 2. **A:** Sagittal CT myelogram revealing L4–5 spinal stenosis *(arrowhead)*. **B:** A 2-level AxiaLIF device on immediate postoperative imaging. **C and D:** Radiolucency surrounding the transaxial rod *(arrowheads)*. **E and F:** Removal of the AxiaLIF device and L4–5 and L5–S1 ALIF. The posterolateral screw-rod construct is extended to the iliac crest. The *asterisk* indicates the cavity of the transsacral rod.

for thoracolumbar scoliosis (T5–L4 with Harrington rods) presented with low-back pain and bilateral hip and thigh pain. A CT myelogram revealed spinal stenosis at L4–5 (Fig. 3A). The patient underwent lumbar decompression and a 2-level AxiaLIF procedure combined with bilateral posterolateral pedicle screw-rod constructs (Fig. 3B). The patient did well, but 2 years after the procedure exacerbation of her low-back pain prompted an imaging study, revealing radiolucency surrounding the AxiaLIF device in the vertebral body of L-4. The symptoms of low-back pain deteriorated over 12 months, and CT imaging revealed increased radiolucency associated with the AxiaLIF as well as loosening of the L-5 and S-1 pedicle screws (Fig. 3C and D). Because of concerns regarding the degree of bone loss surrounding the AxiaLIF, the implant was removed to allow placement of ALIF cages with a large footprint. The interbody cages were filled with Actifuse supplemented with BMP. Revision of the posterolateral construct and extension to the iliac crest was performed (Fig. 3E and F). The patient had an unremarkable postoperative course and is currently doing well.

Case 3

This 67-year-old woman had a history of multiple lumbar spine surgeries complicated by chronic infections and hardware failures. She underwent removal of her hardware (L2–S1) and received an AxiaLIF implant for instrumentation of L4–5 and L5–S1 combined with an L2–S2 pedicle screw-rod construct. Intraoperative cultures grew *Pseudomonas*, and the patient received intravenous antibiotics followed by permanent oral suppression therapy. After 14 months the patient returned with complaints of low-back pain, and a CT scan revealed radiolucency surrounding the left S-2 pedicle screw. The posterolateral pedicle screw-rod construct was revised and extended to the iliac bone using iliac screws. Intraoperative cultures were positive for multidrug-resistant *Klebsiella*, and the antibiotic suppression therapy was adjusted. Nine months later there was failure of both pedicle screw rods at the level of L5–S1, and radiolucency surrounding the axial rod was noted. All implants including the AxiaLIF device were removed, and new posterolateral and anterior instrumentation (ALIF) was implanted using Actifuse graft substitute. The patient tolerated the procedure well and is currently undergoing physical rehabilitation.

Case 4

This 48-year-old man with a previous history of a lumbar laminectomy that led to degenerative changes suffered from low-back pain and left lower-extremity pain. He underwent a 2-level AxiaLIF procedure and posterolateral L3–S1 instrumentation; at L3–4 dynamic instrumentation was chosen without interbody fusion. Initially the patient did well, but 1 year later he experienced low-back pain and tenderness to palpation. A CT scan was obtained and demonstrated radiolucency surrounding the AxiaLIF proximally in the vertebral body of L-4 and pedicle screw at L-3 and S-1. Sixteen months after the initial procedure, the patient underwent surgical revision of the posterolateral pedicle screw-rod construct, and an L3–4 PLIF with Actifuse graft combined with BMP was performed. The patient tolerated the surgery well and is doing well 4 months after the procedure.

Case 5

This 73-year-old man with a history of L3–5 laminectomy and L3–S1 pedicle screw-rod instrumented fusion at another institution presented with adjacent-segment degeneration proximally at L2–3 and nonunion at L5–S1 (Fig. 4A). A transpsoas approach was performed at L2–3 supplemented with a lateral plate, and an AxiaLIF prodecure was undertaken at L5–S1 (Fig. 4B). Continued back pain and worsening leg pain associated with radiolucency around the AxiaLIF device led to revision surgery after 8 months (Fig. 4C and D). At this time a posterior approach was undertaken with further clearance of the intervertebral disc space and insertion of bilateral expandable PEEK cages (Spinewave) using Actifuse graft positioned to either side of the retained AxiaLIF device (Fig. 4E and F). Posterior pedicle screw–based instrumentation was extended to the iliac crest. Twelve months later, CT imaging demonstrated a stable construct and early signs of a fusion mass, and the clinical symptoms are similar to the preoperative assessment.

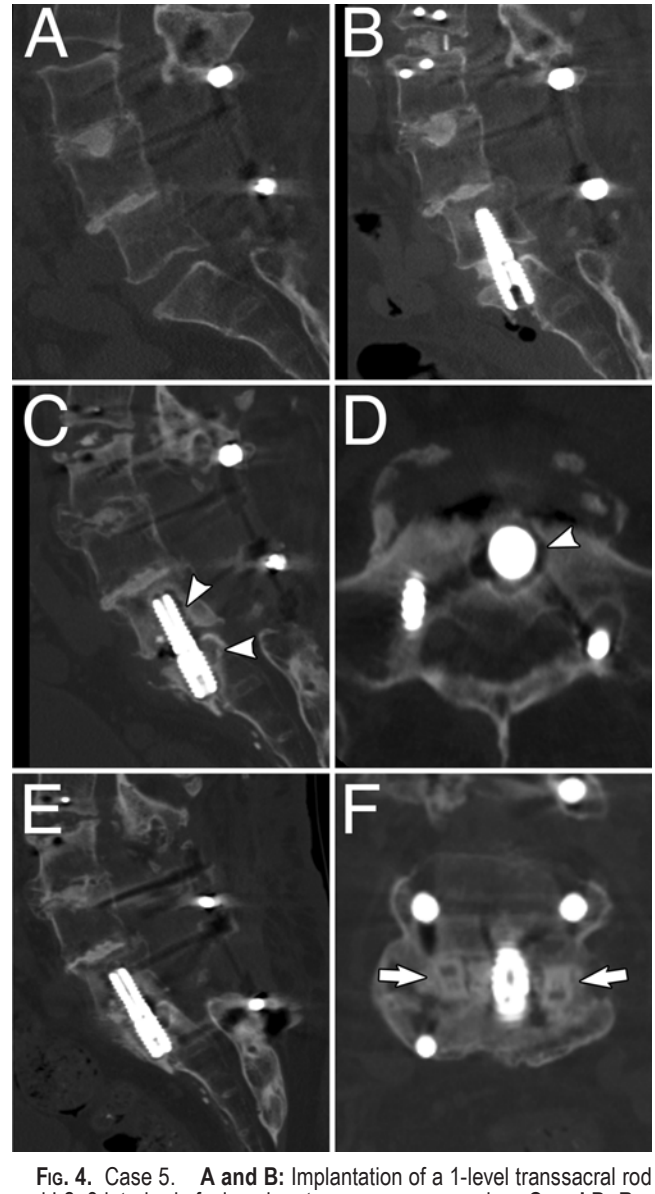


Fig. 4. Case 5. **A and B:** Implantation of a 1-level transsacral rod and L2–3 interbody fusion via a transpsoas approach. **C and D:** Radiolucency surrounding the AxiaLIF device and nonunion of L5–S1 suggestive of pseudarthrosis. **E and F:** Revision by bilateral PLIF with bilateral expandable PEEK cages *(arrows)* resulting in solid bony fusion.

Discussion

In the current study we report our experience with revision of failed AxiaLIF constructs. We provide a step-by-step description of the surgical technique for removal of the device and discuss revision strategies.

Removal of the AxiaLIF Device

Paracoccygeal transsacral fixation is a relatively novel technique.[4,8,12,15] Only 1 case of successful removal of

an AxiaLIF device has been described in the literature.[4] In that case an anterior sacral resection was performed to remove the implant and to stabilize the segment with an ALIF. We describe percutaneous retrieval of the device using the same presacral working corridor as for implantation. The presacral space is bordered anteriorly by visceral fascia that lines the posterior aspect of the mesorectum and posteriorly by parietal fascia that covers the sacrum. Since these planes of dense fascia are not usually violated during initial placement of the device, it is possible to redevelop the surgical corridor for device retrieval by blunt dissection. Moreover, the presacral space is usually devoid of vasculature except for the middle sacral artery, which provides only minor contributions to segmental arteries and may be entirely absent in 15% of cases.[14] However, given the possible increased risk of visceral and vascular injury using the same presacral working corridor, we only recommend removal of the device if clinically necessary. In our 2 cases the removal was straightforward and safe with minimal blood loss and without injury to gastrointestinal structures. Removal was facilitated by 2 intraoperative maneuvers. First, after docking of the blunt guide at the head of the AxiaLIF device, insertion of a guidewire into the hollow core of the device is necessary to maintain position and alignment until the exchange cannula is anchored with a separate guidewire; and second, the AxiaLIF Retrieval Expanding Hex Sub-Assembly was by far the most useful instrument to remove the proximal and distal rod of the AxiaLIF device.

Strategies for Revising AxiaLIF Arthrodesis

Removal of the AxiaLIF device was deemed necessary in 2 patients. Excessive bone resorption around the AxiaLIF device and chronic infection were identified as indications for the removal in our series. In both of these situations we chose to stabilize the anterior column with an ALIF rather than a PLIF because the small footprint of PLIF cages combined with the large bony defect created by the AxiaLIF device would be associated with a high likelihood of graft subsidence. In contrast, the anterior approach allows for the implantation of spacers with a wide contact area decreasing stress concentrations between the cage and the vertebral body, potentially minimizing the risk of graft subsidence. In our series, posterior instrumentation was revised in all failed constructs. When nonunion was evident at the L5–S1 segment, the pedicle screw-rod construct was extended to the iliac crest and the anterior column instrumentation was enhanced by bilateral PLIF at L5–S1. In a case with L4–5 instability we opted for sole revision of the posterior construct. Importantly, we used BMP in combination with Actifuse in all of our revision cases.

How to Avoid Failure of AxiaLIF Constructs

There are lessons to be learned from our revision cases and failed surgeries. We have performed a total of 40 AxiaLIF procedures, and all our failures were observed in multilevel construct and in procedures in which AxiaLIF was part of a revision surgery. Therefore, AxiaLIF may not be an ideal operative approach for revision surgery. In addition, in the setting of a preexisting infection, the AxiaLIF approach may not allow an adequate removal of infected tissue and discectomy, which may be crucial to clear out an infection. Moreover, multisegment fusion constructs may also be more prone to failure. Based on our clinical experience, we believe that 2-level AxiaLIF constructs are biomechanically inferior to ALIF/pedicle screw constructs. Finally, in our initial surgeries bone extender was used for the fusion. Based on the failures we believe that the addition of BMP may facilitate fusion and reduce the rate of nonunions.

Conclusions

In the majority of cases, a posterior approach alone is adequate for revision of failed AxiaLIF constructs. If clinically indicated, the AxiaLIF device may be removed using percutaneous technique followed by ALIF for stabilization of the anterior column. Thus, AxiaLIF appears to be a valuable technique for single-level L5–S1 instrumentation. Safe and effective revision strategies exist.

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: Härtl, Hofstetter. Acquisition of data: Hofstetter, James. Analysis and interpretation of data: all authors. Drafting the article: Hofstetter, James. Critically revising the article: Härtl, James. Reviewed submitted version of manuscript: Härtl. Approved the final version of the manuscript on behalf of all authors: Härtl. Statistical analysis: Härtl, Hofstetter. Study supervision: Härtl.

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Manuscript submitted June 14, 2011.
Accepted August 9, 2011.
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Neurosurg Focus 31 (4):E18, 2011

Abdominal wall paresis as a complication of minimally invasive lateral transpsoas interbody fusion

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Object. The minimally invasive lateral transpsoas approach for interbody fusion has been increasingly employed to treat various spinal pathological entities. Gaining access to the retroperitoneal space and traversing the abdominal wall poses a risk of injury to the major nervous structures. Nerve injury of the abdominal wall can potentially lead to paresis of the abdominal musculature and bulging of the abdominal wall. Abdominal wall nerve injury resulting from the minimally invasive lateral retroperitoneal transpsoas approach has not been previously reported. The authors describe a case series of patients presenting with paresis and bulging of the abdominal wall after undergoing a minimally invasive lateral retroperitoneal approach.

Methods. The authors retrospectively reviewed all patients who underwent a minimally invasive lateral transpsoas approach for interbody fusion and in whom development of abdominal paresis developed; the patients were treated at 4 institutions between 2006 and 2010. All data were recorded including demographics, diagnosis, operative procedure, positioning, hospital course, follow-up, and complications. The onset, as well as resolution of the abdominal paresis, was reviewed.

Results. The authors identified 10 consecutive patients in whom abdominal paresis developed after minimally invasive lateral transpsoas spine surgery out of a total of 568 patients. Twenty-nine interbody levels were fused (range 1–4 levels/patient). There were 4 men and 6 women whose mean age was 54.1 years (range 37–66 years). All patients presented with abdominal paresis 2–6 weeks postoperatively. In 8 of the 10 patients, abdominal wall paresis had resolved by the 6-month follow-up visit. Two patients only had 1 and 4 months of follow-up. No long-term sequelae were identified.

Conclusions. Abdominal wall paresis is a rare but known potential complication of abdominal surgery. The authors report the first case series associated with the minimally invasive lateral transpsoas approach.
(DOI: 10.3171/2011.7.FOCUS11164)

Key Words • **eXtreme Lateral Interbody Fusion** • **abdominal wall paresis** • **direct lateral interbody fusion** • **pseudohernia** • **complication**

Minimally invasive spinal procedures such as the lateral retroperitoneal transpsoas approach are being increasingly used to treat various spinal disorders including degenerative disc disease, spondylolisthesis, spinal deformities, and traumatic spinal injuries. In addition to the inherent risks to the lumbar plexus due to the proximity of the surgical pathway, there is also risk of injuring nerves that travel outside the psoas muscle. Gaining access to the retroperitoneal space and traversing the abdominal wall poses a risk of injury to the major nervous structures and adds significant morbidity to the procedure.

Nerve injury of the abdominal wall results in paresis and bulging of the abdominal musculature. Abdominal wall paresis following laparoscopic surgeries, although rare, has been described.[11,28] To our knowledge, abdominal wall paresis following minimally invasive spinal surgery has not yet been reported in the literature. We present a case series of abdominal wall paresis following the minimally invasive lateral retroperitoneal transpsoas approach and review the relevant anatomy.

Methods

The authors retrospectively reviewed data obtained in all consecutive patients who underwent a minimally invasive lateral retroperitoneal transpsoas approach for interbody fusion and who subsequently developed abdominal paresis. The data were culled records at 4 institutions between 2006 and 2010. All patient data were recorded prospectively including demographics, diagnosis, operative procedure, positioning, hospital course, follow-up, and complications. Each institution was responsible for the collection and maintenance of their databases. The

surgeons were responsible for the reliability and validity of their own database. The onset and resolution of the abdominal paresis were noted.

Results

Between 2006 and 2010 at the 4 centers, we identified 10 consecutive patients in whom abdominal paresis developed after minimally invasive lateral transpsoas spine surgery of a total of 568 patients—an incidence rate of approximately 1.8% (Table 1). These cases were identified on routine physical examinations during follow-up visits. Each patient was examined by his/her surgeon. A total of 29 interbody levels were fused (range of 1–4 levels/patient). There were 4 men and 6 women whose mean age was 54.1 years (range 37–66 years). Primary diagnoses included degenerative disc disease, spondylosis, pseudarthrosis, and adult degenerative and idiopathic scoliosis. All patients presented with complaints of low-back pain, whereas only 4 had a component of radiculopathy. A minimally invasive lateral retroperitoneal approach for interbody fusion was successfully performed in all patients.

All patients later presented with fullness and bulging of the anterior abdominal wall, away from their incisions, and were diagnosed with abdominal paresis 2–6 weeks postoperatively (Table 1). Four patients underwent abdominal CT scanning to confirm that there was no evidence of an abdominal wall defect or hernia. All patients were treated conservatively, with no acute intervention. Eight of the 10 patients had complete resolution of the abdominal wall paresis by the 6-month follow-up visit. Two patients had persistent abdominal wall paresis at last follow-up, which in one was only 1 month and in the other 4 months after presentation. The mean follow-up period was 18.3 months (range 1–40 months). No long-term sequelae were identified.

Illustrative Case

This 66-year-old woman underwent a left-sided minimally invasive lateral retroperitoneal approach to L1–2 and L2–3 for interbody fusion. The patient's hospital course was uneventful and she was discharged to home. Two weeks postoperatively, she had a noticeable fullness and bulging of the anterior abdominal wall on the side of the surgical approach, but away from the incisions (Fig. 1). There was no associated pain or discomfort. This bulge became more pronounced at 4 weeks, and abdominal wall denervation was diagnosed. A CT scan of the abdomen was acquired to confirm that there was no abdominal wall defect or hernia. The patient was treated conservatively with a corset. By 6 months postoperatively, the abdominal wall paresis had completely resolved and the abdomen had returned to a normal appearance. There were no long-term sequelae due to the abdominal wall dysfunction.

Discussion

The minimally invasive lateral retroperitoneal transpsoas approach is increasingly being used to treat various spinal disorders. Although this procedure is safe and reproducible, approach-related neural complications have been reported.[4,10,27,29] The majority of neural complications, secondary to lumbar plexus injuries, occur while traversing the psoas muscle. However, there is inherent risk of direct injury to the main motor nerves that supply the anterior abdominal muscles during the early stages of the minimally invasive lateral retroperitoneal approach while gaining access to the retroperitoneum, traversing the abdominal wall, or bluntly dissecting the retroperitoneum.[5] Injury to these nerves may result in denervation, paresis, and bulging of the anterior abdominal wall. This paresis is typically characterized by swelling and is often associated with pain, hyperesthesia, or other sensory abnormalities. It is sometimes referred to as a "pseudohernia."[6,7,16,21]

One of the main causes of abdominal wall paresis is iatrogenic injury during surgery. It has been reported after abdominal and pelvic surgery.[5,8,11,19,28] Nerve root compression from a herniated disc has also been reported in the literature.[1,18,22] Diabetic neuropathy has also been implicated as an etiological factor of abdominal wall paresis.[3,12,13,30] Infectious causes such as herpes zoster and

TABLE 1: Summary of patient, disease, and treatment characteristics*

Case No.	Age (yrs), Sex	Diagnosis/Pathology	Presenting Sign/ Symptom	Lat Interbody Fusion Levels	No. of Levels	FU (mos)
1	37, F	adult idiopathic scoliosis	LBP	L1–5	4	36
2	56, F	adult idiopathic scoliosis	LBP w/ radiculopathy	L2–5	3	40
3	54, F	adult idiopathic scoliosis	LBP w/ radiculopathy	L1–4	3	33
4	66, F	ASF/ DDD/degenerative scoliosis	LBP	L1–3	2	24
5	65, M	postlaminectomy syndrome, kyphotic deformity, DDD	LBP w/ radiculopathy	L1–5	4	4
6	54, M	pseudarthrosis	LBP	L2–3	1	9
7	53, F	adult degenerative scoliosis	LBP w/ radiculopathy	L2–5	3	6
8	57, F	DDD	LBP	L3–5	2	12
9	46, M	lumbar spondylosis	LBP	L2–5	3	18
10	53, M	adult degenerative scoliosis	LBP	L1–5	4	1

* ASF = adjacent-segment failure; DDD = degenerative disc disease; FU = follow-up; LBP = low-back pain.

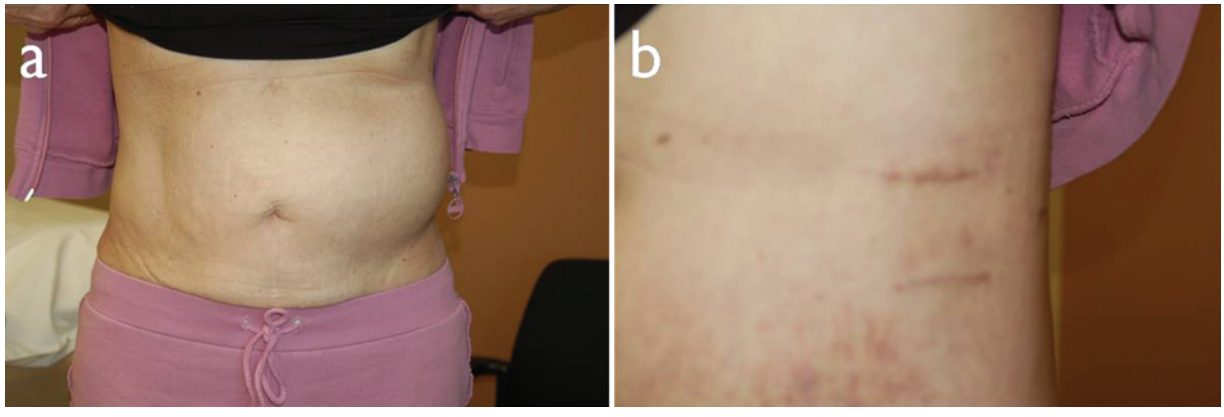


Fig. 1. **a:** Anterior view of abdomen demonstrating bulging and abdominal wall paresis of the left abdominal wall. **b:** Left lateral view of the flank showing well-healed surgical incisions away from the area of abdominal paresis.

lyme disease have been documented to cause neuropathy causing abdominal wall paresis.[9,15,16,20,21,24–26,33]

Although there are many causes of abdominal paresis, treatment remains conservative. Spontaneous recovery of nerve function has been reported in several cases.[18–20] No patient in our case series required any intervention or treatment. The majority of patients improve. Abdominal CT scanning may be performed to exclude the presence of abdominal hernias. Conservative treatment may consist of increasing abdominal support with a fitted corset. In our series, all 6 patients with greater than 6 months of follow-up had full recovery and resolution of their abdominal paresis.

Although abdominal paresis following the minimally invasive lateral retroperitoneal surgery has not been reported, it is a well-known complication of conventional abdominal and gynecological surgery.[2,14,17,23,31] In our series, the overall incidence of this complication was 1.8%. Abdominal paresis has been reported to be the second most common neuropathy following gynecological surgery with a reported incidence of 3.7%.[31] Although this approach-related complication is rare, with knowledge of the anatomy and a meticulous technique, it can be entirely avoided.

Regional Abdominal Anatomy

To prevent such complications, knowledge of the regional anatomy is critical. A brief review of the pertinent anatomy is as follows. The abdominal wall is mainly composed of 4 groups of muscles: the rectus abdominis, internal oblique, external oblique, and transverse abdominis. The pertinent nerves that supply these muscles are the subcostal, iliohypogastric, and ilioinguinal. Their anatomical description, trajectory, and clinical significance have been well described.[5,32] The subcostal nerve originates from the T-12 nerve root and innervates the rectus abdominis and external oblique muscles. The iliohypogastric and ilioinguinal originate from the T-12 and T12–L1 nerve roots, respectively. They innervate the internal oblique and transverse abdominis muscles. All 3 nerves travel freely in the retroperitoneum and course anteriorly and inferiorly as they pierce the abdominal wall muscles.[5,32] When the motor portions of these nerves are injured, it leads to paralysis of the muscles that are supplied by them and subsequent weakening of the abdominal wall.

There are several limitations to this study. As a retrospective review, there is a risk of a selection bias, but the databases were collected prospectively, and all consecutive patients were included in the study. Also, we reviewed a large cohort that included 568 patients from 4 treatment centers.

Complication Avoidance

The location and trajectories of these nerves place them at significant risk during the early stages of the minimally invasive lateral retroperitoneal transpsoas approach. The nerves can be directly injured while accessing the retroperitoneum during the flank or lateral incision, while dissecting the abdominal muscle wall, or while performing blunt digital dissection of the retroperitoneal cavity. We advocate a combination of useful adjuncts to minimize nerve injuries directly or indirectly during the approach. During the early stages of the approach, once the external oblique muscle fascia is sharply dissected, the dissection of the abdominal wall muscles requires special care. We suggest sequential and gentle muscle dilation with blunt instruments (hemostat forceps) until the retroperitoneal cavity is identified. If a nerve branch is found during the dissection, it is possible to dissect it and mobilize it without causing direct injury. Once the retroperitoneal space is accessed, the blunt dissection of the retroperitoneal space requires gentle development of the space from posterior to anterior and superior to inferior to avoid injuring the main nerves that run freely in the retroperitoneal cavity. While dissecting the retroperitoneum bluntly with the finger, one must be careful not to confuse a free-running nerve in the retroperitoneal fat for an adhesion and avulse or injure it.

Conclusions

Abdominal wall paresis is a rare complication of minimally invasive lateral spinal surgery. We report, to the best of our knowledge, the first case series in the literature. Knowledge of the anatomy of the abdominal wall muscles and the traversing motor nerves that supply them

is very crucial to avoid damaging these nerves. Injury to these nerves may result in paresis and bulging of the anterior abdominal wall.

Disclosure

Dr. A. X. Le is an owner of Phygen Spine and consults for Nuvasive. Dr. Smith consults for Nuvasive. Dr. Akbarnia consults for Nuvasive, K2M, and DuPuy Spine; is an owner of Phygen Spine; and receives clinical or research support from K2M, Nuvasive, and DePuy Spine. Dr. Uribe consults for Nuvasive.

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper. Conception and design: Uribe. Acquisition of data: Dakwar, TV Le, Baaj, AX Le, Smith, Akbarnia. Analysis and interpretation of data: Uribe. Drafting the article: Dakwar. Critically revising the article: Dakwar. Reviewed submitted version of manuscript: Dakwar, TV Le, Baaj, Uribe. Approved the final version of the manuscript on behalf of all authors: Dakwar. Study supervision: Uribe.

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Manuscript submitted June 16, 2011.
Accepted July 21, 2011.

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Neurosurg Focus 31 (4):E19, 2011

Cervical juxtafacet cyst after anterior cervical discectomy and fusion

Case report

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Anterior cervical discectomy and fusion (ACDF) is a common neurosurgical procedure, and the benefits, long-term outcomes, and complications are well described in the literature. The development of a juxtafacet joint cyst resulting in radiculopathy is a rare outcome after ACDF and merits further description. The authors describe a patient in whom a juxtafacet joint cyst developed after ACDF procedures, resulting in surgical intervention. When a juxtafacet joint cyst develops after ACDF, symptoms can include radiculopathy, neck pain, and neurological symptoms such as paresthesias and motor weakness. The presence of a juxtafacet joint cyst implies instability in that region of the spine. Patients with this pathological entity may require decompression of neural elements and fusion across the segment involved with the cyst. *(DOI: 10.3171/2011.8.FOCUS11119)*

Key Words • **cervical juxtafacet cyst** • **anterior cervical discectomy and fusion** • **synovial facet joint cyst** • **transitional syndrome** • **adjacent-segment disease** • **spinal cord**

The term "juxtafacet cyst" was coined by Kao et al.[28] in 1974 to describe a cyst arising from the joint capsule of a spinal facet joint. Although this is a rare pathological condition, juxtafacet cysts can be a cause of significant morbidity. Cysts arising in this location can be classified histologically either as synovial cysts, containing a true synovial lining, or as ganglion cysts, implying an absence of the synovial lining.[5] These cysts can cause myelopathy, radiculopathy, and neck pain because of mass effect on the spinal cord or nerve root compression.[9] These extradural cysts are almost exclusively found in the lumbar spine, with only 37 cases identified as occurring in the cervical spine from a variety of causes.[1,2,6–8,11,14,16,19,20,23,26,27,29,31,35–40,43,45–49,51–53]

Over the last 2 decades, ACDF has become one of the most common neurosurgical procedures. As spinal hardware has improved and as literature on this topic has mounted, the techniques for the procedure have changed, and ACDFs incorporating more segments can now be performed.[17] Although reported complications from these procedures are uncommon and typically minor, both short- and long-term adverse events have been described. Long-term follow-up of patients indicates that symptomatic ASD is a potential sequela of long-segment ACDF.[25] Symptomatic ASD rates are typically reported to range from 7% to 19% after up to 10 years of monitoring.[24,32] When patients without symptoms are included, postoperative degenerative changes at adjacent segments can be identified radiographically in 50%–60% of patients by the 4-year follow-up.[22,25,50] Juxtafacet cysts in the cervical region at a segment adjacent to a spinal fusion construct probably represent one form of ASD. We present a case of juxtafacet cyst causing symptomatic ASD at the cervicothoracic junction after long-segment ACDF.

Abbreviations used in this paper: ACDF = anterior cervical discectomy and fusion; ASD = adjacent-segment disease.

Case Report

History and Examination. This 67-year-old woman with a history of breast carcinoma presented to our spine tumor clinic due to 6 months of intense tingling accompanied by occasional numbness overlying the fourth and fifth digits of her left hand. There were instances in which this tingling became painful and pressure-like. Of note, she had been involved in a motor vehicle accident 15 years

earlier that had required a C4–7 anterior decompression and interbody bone graft fusion. On examination, motor strength was decreased in her left upper extremity, specifically her grip. Imaging revealed a facet joint cyst causing compression of the thecal sac on the left side and C-8 root impingement (Fig. 1).

Operation and Postoperative Course. The patient underwent a C7–T1 hemilaminectomy, partial facetectomy, and posterior segmental fixation of C5–T2 with placement of autologous graft. Intraoperatively, the lesion was found to be densely adherent to the dura mater and was sharply dissected from the C-8 nerve root. Pathological analysis confirmed reactive synovium-lined connective tissue consistent with synovial cyst. Postoperatively, the patient's condition improved rapidly. At the 1-month follow-up visit, her arm symptoms had completely resolved, and she had regained full strength in her left upper extremity. At 6 months after surgery, she continued to be free of neurological symptoms.

Discussion

Juxtafacet cysts, either synovial or ganglion cysts, although common in many joint and tendon sheaths in the body, are relatively uncommon in the spine. Most occur within the thoracic and lumbar spine, with far fewer occurring in the cervical region.[47] Only 37 cases of cervical juxtafacet joint cysts have been reported previously in the literature (Table 1).

In a case report and literature review published in 1999, Lunardi et al.[31] presented theories regarding the cause of juxtafacet cysts of the spine. Various authors have proposed that the genesis of these cysts may involve degeneration, inflammation, congenital defects, and trauma. Although occasional reports have appeared stating that hemosiderin deposits, indicating old hemorrhage, have been found within these cysts on pathological evaluation, trauma is not believed to be a primary cause.[18,44] Additionally, rare reports document synovial cysts arising at periarticular fibroconnective tissue in patients with rheumatoid arthritis, which supports an inflammatory or congenital cause.[30] Numerous authors, however, endorse the idea that synovial cysts are the result of increased movement at the spinal synovial joint and of subsequent degeneration and cyst formation of the synovium.[31,41,44] Although several factors may play a role in the progression of this disease, our case provides further evidence for the degenerative model of synovial cyst formation.

The ACDF procedure has become one of the most common operations for cervical radiculopathy or myelopathy in patients in whom conservative treatment has failed. Since the operation was first described by Cloward[10] in 1958, the rates of arthrodesis and positive clinical outcome have significantly improved for single-level procedures, with refinements in plating systems resulting in improved multilevel outcomes. Success rates of this procedure have been cited as high as 95%.[3]

In the immediate period after ACDF, postoperative dysphagia, postoperative hematoma, recurrent laryngeal nerve injury, arterial dissection, esophageal perforation, spinal cord contusion, and persistent postoperative pain are all known to occur. With the increased use of this procedure, however, long-term complications have also become clearly evident. Signs of radiculopathy or myelopathy that can be attributed to the segment adjacent to a previous spinal arthrodesis are referred to as ASD or transitional syndrome. There has been a significant increase in the incidence of this condition during the past 50 years, probably stemming from the increased

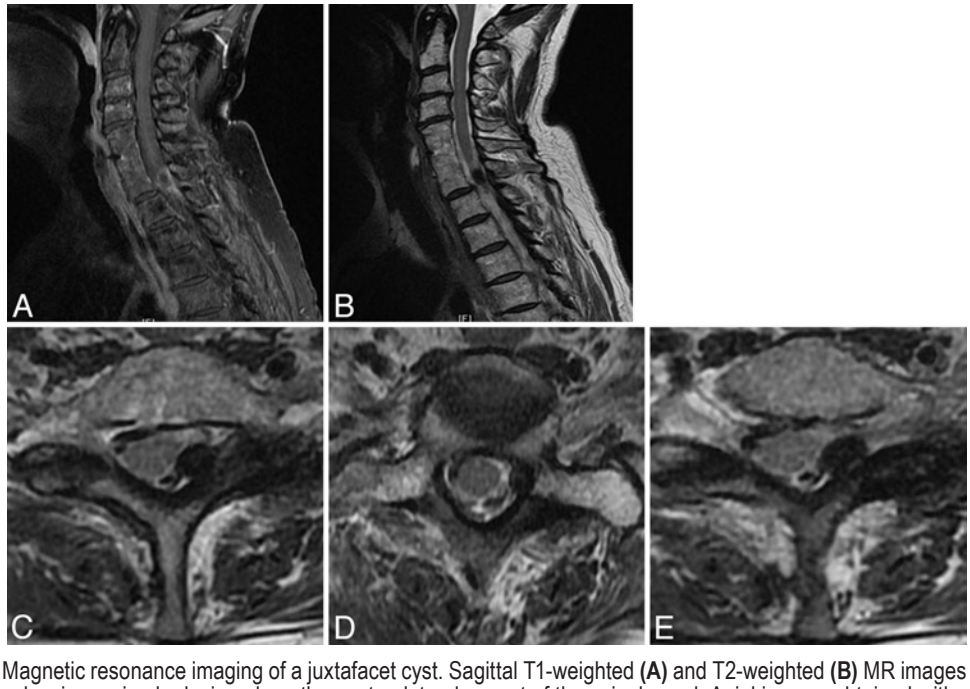


Fig. 1. Magnetic resonance imaging of a juxtafacet cyst. Sagittal T1-weighted **(A)** and T2-weighted **(B)** MR images of the cervical spine showing a circular lesion along the posterolateral aspect of the spinal canal. Axial images obtained without contrast **(C–E)** illustrate compression of the left C-8 nerve root by the cyst.

TABLE 1: Literature review of cases of juxtafacet joint cysts of the cervical spine*

Authors & Year	No. of Pts	Age (yrs), Sex	Level	Clinical Manifestation	Neuro Study	Findings	Intervention
Aksoy & Gomori, 2000	1	61, M	C1–2	C, M	MRI	C-2: cyst extension, cord compression	C1–2: laminectomy & ant fusion
Birch et al., 1996	1	85, M	C1–2	M, R	MRI	dens: extradural mass, no cord compression	dens: transoral decompression; C1–2: fusion
	1	84, F	C1–2	M	MRI	dens: extradural mass, cord compression	C1–2: hemilaminectomy
	1	60, F	C1–2	M	MRI	dens: extradural mass, cord compression	C1–2: hemilaminectomy
	1	78, F	C1–2	M, R	MRI	dens: extradural mass, cord compression	observation
	1	68, F	C1–2	M, R	CT, MRI	dens: extradural mass, cord compression	dens: transoral decompression; C1–2: fusion
Cartwright et al., 1985	1	41, M	C7–T1	M	CT	C7–T1: midsagittal narrowing of cervical canal	C6–T1: decompressive laminectomy
Cho et al., 2004	1	80, M	C7–T1	M, R	MRI	C7–T1: mass w/ neuraxial structure compression	C-7: laminectomy
Choe et al., 1993	1	61, M	C1–2	M	MRI	dens: large mass, cord compression	C-1: laminectomy
Costa et al., 2010	1	84, M	C7–T1	R	CT, MRI	C-7: extradural lesion, no cord compression	C-7: rt hemilaminectomy; C6–T1: partial laminectomy
Epstein & Hollingsworth, 1993	1	47, M	C7–T1	M, R	CT, MRI, myelo	C7–T1: ovoid soft-tissue mass, cord compression	C7–T1: hemilaminectomy
Fonoff et al., 2004	1	64, M	C3–4	M, R	CT, MRI	C3–4: calcified lesion, severe cord compression	C-3: pst hemilaminectomy
Fransen et al., 1997	1	75, F	dens	M, R	MRI	dens: cystic mass, cord compression	C1–2: pst hemilaminectomy, suboccipital hemicraniectomy
Freidberg et al., 1994	1	NR	C7–T1	M	MRI		C7–T1: laminectomy
Goffin et al., 1992	1	65, M	C1–2	M	CT, myelo	soft-tissue mass, cord compression	C1–2: laminectomy
Jost et al., 2003	1	72, F	C6–7	R	MRI	C-6: cystic lesion, no cord compression	C-5/6 & C-6/7: ant discectomy; C-6: hemicorpectomy; C5–7: ant fusion
Kao et al., 1974	1	52, M	C6–7	R	myelo	C-7: nerve root sleeve defect	C6–7: hemilaminectomy
Kaiser & Holland, 1998	1	74, M	C4–5	R	CT	C-5: epidural mass	C4–5: laminectomy
Kotilainen & Marttila, 1997	1	64, M	C7–T1	M	NA		C-7: laminectomy
Lunardi et al., 1999	1	58, M	C7–T1	M	CT, MRI	C7–T1: hypodense cystic lesion, neuraxial structure compression	C7–T1: laminectomy
Miller et al., 1989	1	67, F	C1–2	M	CT, myelo	C1–2: anterolat mass, cord compression	C1–2: laminectomy, removal of foramen magnum rim
Miwa et al., 2004	1	74, F	C7–T1	M	MRI	C7–T1: cystic lesion, mild cord compression	C7–T1: hemilaminectomy
Morio et al., 2003	1	71, F	C1–2	M, R	MRI	dens: large cystic mass, cord compression	C1–2: pst fusion
Nijensohn et al., 1990	1	58, M	C4–5	M, R	CT, myelo, MRI	C5–6: calcified extradural lesion, cord compression	C-5: decompression; C4–6: pst fusion
Okamoto et al., 2004	1	72, M	C1–2	M, R	MRI	C1–2: large cystic mass, cord compression	C1–2: hemilaminectomy, pst fusion
Onofrio & Mih, 1988	1	73, M	C1–2	M	CT, myelo	upper cervical cord lesion	C1–2: laminectomy, suboccipital craniectomy
Patel & Sanders, 1988	1	42, F	C4–5	R	stratigraphy		C-4: hemilaminectomy
Quaghebeur & Jeffree, 1992	1	82, M	C1–2	M	CT, myelo		C1–2: laminectomy
Shima et al., 2002	3	66, M/68, M/72, F	C7–T1	M/R/M	CT/myelo/MRI	C7–T1: extradural cystic mass	C7–T1 laminectomy/C-7 laminectomy/C-7 laminectomy

(continued)

TABLE 1: Literature review of cases of juxtafacet joint cysts of the cervical spine* *(continued)*

Authors & Year	No. of Pts	Age (yrs), Sex	Level	Clinical Manifestation	Neuro Study	Findings	Intervention
Song et al., 2006	1	74, M	C7–T1	M	MRI	C7–T1: cystic mass	C7–T1: hemilaminectomy
Stoodley et al., 2000	1	65, M	C7–T1	C, M	CT, MRI	C7–T1: calcified lesion	C6–T1: laminectomy
Takano et al., 1992	1	72, M	C3–4	M, R	CT, MRI	mass, cord compression	C3–6: laminectomy
Vastagh et al., 2008	1	44, M	C7–T1	M, R	CT, MRI	cyst, cord compression	C7–T1: hemilaminectomy
Vergne et al., 1996	1	64, F	C1–2	M	NA		C-1: laminectomy
Weymann et al., 1993	1	NR	C1–2	M	NA		C-1: laminectomy
present study	1	67, F	C7–T1	M, R	CT, MRI	C7–T1: facet joint cyst, nerve root impingement	C7–T1: hemilaminectomy, partial facetectomy, C5–T2 fixation

* ant = anterior; C = claudication; M = myelopathy; myelo = myelography; NA = not available; Neuro = neuroimaging; NR = not reported; pst = posterior; pts = patients; R = radiculopathy.

number of radiographic studies, more uniform use of the procedure, and longer survival times for its patients.[42] Adjacent-segment disease has been shown in retrospective analysis to be present radiographically in upwards of 60% of patients.[25] Specifically related to ACDF, Baba et al.[4] noted progressive spinal stenosis in 25% of patients who received the procedure over an average of 8.5 years, whereas Goffin et al.[21] noted an incidence of radiographically apparent adjacent-segment degeneration in 92% of patients at a minimum 5-years follow-up. The majority of these patients, however, were not symptomatic; only 6% required repeat operation.

The cause of ASD is still debatable; however, there are ample data suggesting that biomechanical alterations as a result cervical fusion contribute to its pathophysiology. Studies using radiography, fluoroscopy, or biomechanical testing have demonstrated increases in motion immediately adjacent to fixation levels.[4,12,15] In addition, cadaveric specimens, flexion-extension films, and finite-element analysis have all alluded to increased strain on motion segments in proximity to sites of arthrodesis.[13,33,34] Under even normal circumstances, chronic exposure of these motion segments to increased stress and load may result in their progressive degeneration, failure, and symptomatic disease.

In the case we describe, the juxtafacet cyst found after a previous long-segment ACDF probably represents a form of ASD. Interestingly, it was located at the cervicothoracic junction, which represents a significant zone of stress between the mobile cervical spine and the fixed thoracic spine, as well as a location where cervical lordosis transitions to thoracic kyphosis. After long-segment cervical fusion, the range of motion of the cervical spine becomes noticeably restricted. As a result, over the course of several years, there is increased movement at the spinal segments adjacent to the fusion and disproportionate subsequent degeneration of the respective facet joint synovium. Cyst formation represents a possible sequela of this chronic process.

Conclusions

Improvements in spinal stability technology, surgical experience, and surgical technique continue to lead to increased use of ACDF, with better clinical outcomes. Longer subsequent follow-up will probably reveal a higher rate of ASD, which can present as spinal canal stenosis, osteophytes, disc degeneration, and, as described, juxtafacet cysts. Although rare, these cysts can be a cause of significant morbidity, and should be considered in patients who have had previous spine surgery and present with recurrent symptoms. If the cyst is discovered and its components can be completely removed during surgery, patients appear to achieve a progression-free postoperative course. Further study will be needed to elucidate the factors important for cyst development.

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: all authors. Acquisition of data: all authors. Analysis and interpretation of data: Sivakumar, Elder. Drafting the article: all authors. Critically revising the article: all authors. Reviewed submitted version of manuscript: Sivakumar, Elder. Approved the final version of the manuscript on behalf of all authors: Bilsky. Study supervision: Bilsky.

Acknowledgment

The authors thank Kristin Kraus, M.Sc., for editorial assistance in preparing this article.

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Manuscript submitted June 2, 2011.
Accepted August 3, 2011.

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Neurosurg Focus 31 (4):E20, 2011

Idiopathic intracranial hypertension following spinal deformity surgery in children

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Idiopathic intracranial hypertension (IIH) after pediatric spinal deformity surgery has not been previously reported. The authors conducted a retrospective analysis of more than 1500 pediatric spinal surgeries performed between 1992 and 2011. From their analysis, they report on 3 adolescent patients who underwent uncomplicated segmental spinal instrumentation for pediatric spinal deformity correction and subsequently developed features of IIH. The common variables in these 3 patients were adolescent age, spinal deformity, being overweight, symptom onset within 2 weeks postoperatively, significant estimated blood loss, and intraoperative use of ε–aminocaproic acid (antifibrinolytic) injection. The authors postulate that the development of IIH could be the result of venous outflow obstruction due to derangement of the epidural venous plexus during surgery. The use of ε–aminocaproic acid could potentially have the risk of causing IIH, probably mediated through hyperfibrinogenemia, although there have not been published cases in the neurosurgical, orthopedic, cardiac, or general surgical literature. Idiopathic intracranial hypertension after spinal deformity correction is a condition that should be recognized by neurosurgeons and orthopedic surgeons, because appropriate intervention with early medical therapy can lead to a satisfactory clinical outcome. *(DOI: 10.3171/2011.7.FOCUS11160)*

Key Words • **idiopathic intracranial hypertension** • **idiopathic scoliosis** • **posterior spinal fusion** • **segmental spinal instrumentation** • **antifibrinolytic therapy** • **hyperfibrinogenemia**

Idiopathic intracranial hypertension is an uncommon but potentially devastating disorder in the pediatric population.[1,2,7–9,15] First described by Heinrich Irenaeus Quincke[33] in 1893 as "serous meningitis," this poorly understood disease process has changed names multiple times, alternately referred to as pseudotumor cerebri, otitic hydrocephalus, and benign intracranial hypertension. However, the term "idiopathic intracranial hypertension" has been maintained since Corbett and Thompson's description in 1989,[9] as the exact etiology and pathophysiology remains uncertain.[7,8,24,41–43] Among the implicated causes are the following agents: vitamin A, tetracycline, oral contraceptive pills, lithium carbonate, recombinant human growth hormone, cimetidine, and amiodarone. Endocrinological causes that have been postulated are obesity, pregnancy, menarche, adrenal steroid withdrawal, and hyperadrenalism.[35,38] There are some hematological and connective tissue disorders associated with development of IIH such as iron-deficiency anemia, infectious mononucleosis, lupus, hypothyroidism, hypoparathyroidism, Cushing disease, adrenal insufficiency, and Wiskott-Aldrich syndrome.[22,23] Neurological causes for venous outflow obstruction such as transverse sinus thrombosis, mastoiditis, head trauma, marantic sinus thrombosis, and hyperfibrinogenemia have also been implicated.[23]

Patients with IIH often present with headache or dizziness and visual disturbances including blurred vision and diplopia.[15] The incidence of IIH was reported in a study from the Mayo Clinic (Rochester, MN) as 0.9 case per 100,000 population (1.6 cases per 100,000 women, 3.3 cases per 100,000 female patients 15–44 years of age, and 7.9 cases per 100,000 obese female patients 15–44 years of age).[34] Diagnostic criteria for IIH were set forth by Friedman and Jacobson[18] in 2002. It is a syndrome of elevated ICP without hydrocephalus or mass lesion, with normal CSF composition.[4,18,21] Before lumbar puncture can safely be performed, MR images or CT studies should be obtained to identify any mass lesions that could result in brain shift or uncal herniation.[4] The cutoff limit for abnormal ICP has been considered to be greater than 250 mm H_2O; pressure in cases of IIH has sometimes

Abbreviations used in this paper: EACA = ε–aminocaproic acid; ICP = intracranial pressure; IIH = idiopathic intracranial hypertension; PSF = posterior spinal fusion.

been reported at 2 or 3 times that number.[38] Permanent severe visual disturbance occurs in cases of undiagnosed IIH in up to 24% of cases that have been monitored for 5–41 years.[43]

We present 3 cases of IIH in a previously unreported setting of pediatric spinal deformity correction surgery (Table 1). The aim of the current report is to alert neurological and orthopedic surgeons that visual disturbances and headaches in the early postoperative period can represent a serious, but treatable, condition. In addition, we propose a possible explanation for these cases based on the current literature.

Case Reports

Case 1

This 13-year-old girl presented in 2009 with esotropia, diplopia, tinnitus, and headache. Her symptoms had started 2 weeks after PSF with segmental spinal instrumentation from T-3 to L-4 for idiopathic scoliosis (T2–6 left apex 26°, T6–11 right apex 42°, and T11–L4 left apex 49°). The intraoperative blood loss was 1 L, and the patient received 1 U of autologous blood. Epsilon–aminocaproic acid was administered intraoperatively. Hospitalization medications included morphine, Dilaudid, piperacillin-tazobactam, and ondansetron. She was discharged home on postoperative Day 5 and was given acetaminophen with codeine for pain.

The patient's medical history was significant for systemic hypertension and prior myringotomy tubes as an infant for recurrent otitis media. Physical examination showed bilateral papilledema and left esotropia with no visual acuity changes. Findings from cranial MR imaging, MR venography, and contrast-enhanced CT scanning of the head were found to be unremarkable. Lumbar puncture showed an opening pressure of 390 mm H_2O. The CSF glucose was 57 mg/dl and protein was 29 mg/dl, and cultures never grew any organisms. The patient was placed on a regimen of acetazolamide 250 mg twice daily, and her headache and diplopia resolved in a period of 6 weeks.

Case 2

This 13-year-old girl presented to the emergency department in 1999 with a 4-day history of constant left parietal headache, episodic diplopia, and blurred vision in the right eye. Her symptoms developed 2 weeks following a PSF and a hybrid segmental spinal instrumentation from T-5 to L-3 for a progressive thoracolumbar scoliosis with a T10–L3 curve of 57° (Fig. 1). The perioperative blood loss was 1500 ml. The patient underwent a blood transfusion using cell saver blood and received 1 U of autologous packed red blood cells along with intraoperative EACA. The patient's medical history was significant for a sacral teratoma removed at 3 days of age. She had developed precocious puberty at 5 years. Examination in the emergency department showed a visual acuity of 20/70 vision (right eye) and 20/20 (left eye). She was afebrile and had no signs of infection. She was sent home from the emergency department with a prescription for ergotamine and caffeine, and it was advised that she follow up with the ophthalmology and neurology services in the next few days. On the 13th postoperative day, the patient remained normal neurologically. However, her eye examination showed bilateral papilledema, and visual testing demonstrated 20/100 vision (right eye) and 20/20 (left eye). There was a central scotoma in the right eye with an afferent pupillary defect, and a right sixth cranial nerve palsy was noted.

Magnetic resonance imaging findings of the head and entire spine were unremarkable (Fig. 2). Lumbar puncture showed an opening pressure of 400 mm H_2O, and the patient was placed on a regimen of acetazolamide 500 mg initially, which increased to 1 g per day with resolution of her headache. Her visual field defects improved over the course of the next 3 months. At 2 years postoperatively, her visual acuity was 20/40 (left eye) and 20/20 (right eye).

Case 3

This 16-year-old boy presented in 2008 on postoperative Day 18 with a progressive worsening severe headache along with vomiting, photophobia, and blurry vision that lasted for 3 days. He had undergone anterior discectomy and fusion from T-6 to T-10 for T-8 to T-9 disc herniation and deformity correction by PSF and from T-2 to L-3 for Scheuermann kyphosis with a progressive 84° curve of thoracic kyphosis (Fig. 3).

The patient's medical history was significant for Asperger syndrome, systemic hypertension, obesity, and dysthymic disorder. He also had a history of recurrent otitis media as a child, requiring myringotomy tubes. Active medications on admission included sertraline, iron, and amlodipine. He had an intraoperative blood loss of 1150 ml

TABLE 1: Summary of characteristics in 3 patients with IIH after spinal instrumentation*

Case No.	Age (yrs), Sex	Medical History	Diagnosis	Levels of Spinal Fusion	Op Time	EBL (ml)	EACA Given	BMI (kg/m^2)	Treatment, Outcome
1	13, F	hypertension, recurrent otitis media	scoliosis	T3–L4	7 hrs, 30 min	1000	yes	24	6 wks of acetazolamide, cured
2	13, F	sacral teratoma, precocious puberty	scoliosis	T5–L3	6 hrs	1500	yes	27	2 mos of acetazolamide, cured
3	16, M	Asperger syndrome, dysthymic disorder, obesity, hypertension	Scheuermann kyphosis	T2–L3	8 hrs, 50 min	1150	yes	31.4	1 mo of acetazolamide, asymptomatic w/ persistent fundus changes of papilledema

* BMI = body mass index; EBL = estimated blood loss.



Fig. 1. Case 2. Preoperative **(left)** and postoperative **(right)** images showing thoracic scoliosis.

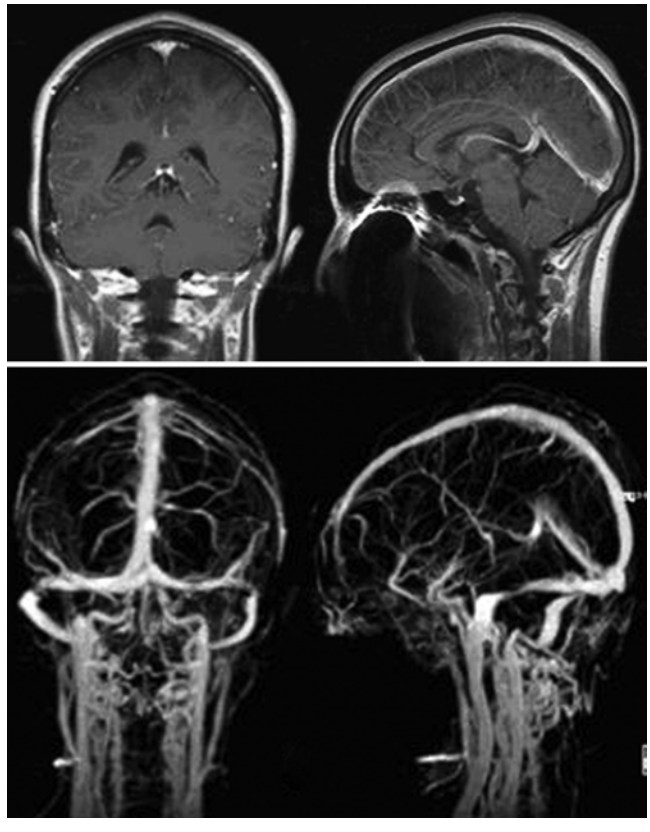


Fig. 2. Case 2. Cranial MR images **(upper)** with corresponding MR venography images **(lower)**, which showed no venous sinus thrombosis.

and received EACA during surgery for blood conservation. Postoperatively, he was started on duloxetine and pregabalin for back pain, along with home medication. Other medications included morphine and hydromorphone for pain.

Examination in the emergency department showed bilateral papilledema and normal visual acuity in both eyes, but later during the admission there was an abnormal enlargement of the blind spot in the left eye noted on formal visual field testing.

Findings from cranial CT and MR imaging including MR venography were normal (Fig. 4). A lumbar puncture showed an increased opening pressure of 330 mm H_2O. The diagnosis of IIH was made, and the patient was treated with acetazolamide 500 mg twice daily with an additional 250 mg at noon (total 1250 mg/day) and pregabalin 150 mg twice daily. Topiramate 25 mg daily and oxycodone 30 mg twice daily were also prescribed for pain control, while he was maintained on his home doses of sertraline and amlodipine. Hematology workup indicated that he was homozygous for methylenetetrahydrofolate reductase (MTHFR) enzyme deficiency, resulting in elevated levels of homocysteine; he was started on a regimen of folic acid. His headache resolved, and visual acuity and fields returned to normal. However, the papilledema persisted for about 2 years postoperatively.

Discussion

Idiopathic intracranial hypertension is a condition characterized by increased ICP in the absence of clinical, laboratory, or radiographic evidence of CNS infection, vascular malformation, intracranial space-occupying lesion, or ventricular dilation.[17,19,20] The exact nature and pathogenesis of the disorder has yet to be elucidated; however, the natural history leads to persistent headache and ensuing visual acuity loss. Idiopathic intracranial hypertension among young children has been associated with several new etiologies, including recombinant growth hormone and all-*trans* retinoic acid.[6,12,15,49] The diagnosis of optic nerve involvement is made using automated perimetry and more recently, optical coherence tomography, laser scanning tomography, and spectral Doppler blood flow analysis of the optic nerve head. More modern neuroimaging techniques such as MR imaging, MR venography, and auto-triggered-elliptic-centric-ordered (ATECO) 3D MR venography are being used to evaluate intracranial processes such as venous sinus thrombosis.[4] In cases of IIH in which there is a high suspicion of sinus thrombosis, procedures such as conventional cerebral angiography, direct retrograde cerebral venography, and manometry are performed to characterize their morphological features and venous pressures, to perform a therapeutic balloon venoplasty or endoluminal venous sinus stenting if necessary.[4,16,30–32] Although most children with IIH improve with medical treatment, those who have had visual progression despite medical treatment have undergone optic nerve sheath fenestration and lumboperitoneal shunting or even ventriculoperitoneal shunting in certain cases.[38]

All patients reported on in our series were of similar age and body habitus, and all had a preexisting spinal deformity. Their IIH symptoms developed approximately 2

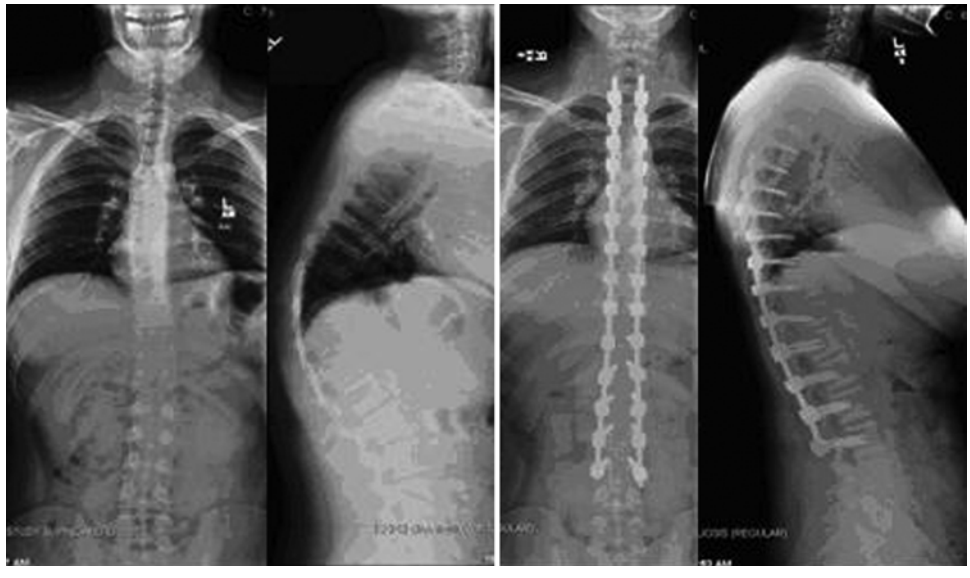


Fig. 3. Case 3. Radiographs (anteroposterior and lateral full-length scoliosis images) obtained before **(left panels)** and after **(right panels)** segmental stabilization surgery.

weeks after elective uncomplicated spinal deformity surgery with a moderate amount of intraoperative blood loss that required transfusion with cell saver and autologous blood in each case. Each patient presented with clearly definable IIH based on the criteria set forth by Friedman and Jacobson.[18] There are no previously reported cases of this intracranial condition occurring in spinal deformity surgery. In 1995, a similar presentation was reported by Daftari et al.[10] in the setting of occipitocervical arthrodesis for persistent nonunion of an odontoid fracture following multiple operations to treat a trauma-related injury. The patient in that report was a thin young woman in her 20s with neck pain and upper-extremity myopathy and sensory neuropathy, which is in contrast to the typical IIH presentation in obese women of childbearing-age presenting with vision-threatening headache.[12,45]

The final common mechanism for IIH has been suggested as an elevation in intracranial venous pressure in a retrospective analysis of 10 patients (children and young adults) with IIH symptoms who required surgical intervention.[26] Measurements were made of central venous pressure as well as ICP, and it was observed that 5 patients had dural venous outflow obstruction and 5 patients had normal venous anatomy with elevated right atrial pressure and venous sinus pressure. The authors suggested that the elevated intracranial venous pressure is the universal common pathway to explain IIH due to "various etiologies." To further illustrate this concept, the same mechanism has been shown to work in the progression of certain types of hydrocephalus.[36,37]

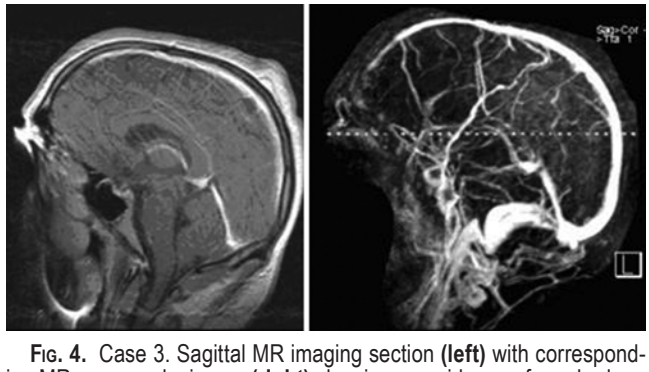


Fig. 4. Case 3. Sagittal MR imaging section **(left)** with corresponding MR venography image **(right)** showing no evidence of cerebral venous sinus thrombosis.

Significant debate continues about the etiopathogenesis of IIH.[29] Dandy[11] postulated that the volume of either CSF or blood might be increased in pseudotumor cerebri. Foley[14] also hypothesized an increase in cerebral blood flow in these cases. Sahs and Joynt[41] demonstrated microscopic evidence of intracellular and extracellular edema in pseudotumor cases. Johnston et al.[25] suggested a defective CSF absorption from increased sagittal sinus pressure as a cause for IIH. Malm et al.[28] postulated that the high CSF pressure in IIH resulted from an increase in sagittal sinus pressure or a decreased CSF conductance. The concepts of venous outflow impairment and cerebral venous hyperemia have been implicated. There is also a suggestion that these patients can be divided on the basis of body habitus; thin patients are more likely to demonstrate venous hyperemia and obese patients have venous outflow impairment given a subtle underlying increase in right atrial pressure.[2,3,30,36,37,45] There are several theories proposed to have a direct link between obesity and IIH, through a specific fat distribution in the body or through production of lipokines, while some others have suggested a converse causation with raised ICP actually causing obesity.[3,5,6,12,45]

Over the years, venous obstruction has been reported by authors to cause hydrocephalus in babies. These authors include Shulman and Ransohoff,[44] Rosman and Shands,[39] and Bateman et al.[3] Likewise, venous outflow obstruction has been implicated in IIH by Karahalios et al.,[26] King et al.,[27] Owler et al.,[32] and Bateman et al.[3] With the advent of direct retrograde cerebral venography and venous sinus manometry, as well as studies with simultaneous measurement of CSF pressures, it has been re-

ported that CSF pressure can be reduced by relieving a venous sinus obstruction causing venous hypertension of the superior sagittal sinus.[32] Given the fact that 80% of the intracranial vascular compliance is provided by the venous system, we believe that the alterations in venous return due to distortion or displacement of vertebral venous plexus during extensive spinal surgery could have a contributory effect for developing IIH in our patients. The reduction of high ICP and the favorable clinical response seen in IIH with acetazolamide would be explained by an increase in venous compliance.[32]

It is unclear whether the use of EACA as a blood conservation agent may play an indirect role in the development of IIH. Epsilon–aminocaproic acid is a 6-aminohexanoic acid belonging to the lysine class of antifibrinolytic agents. This agent can bind the lysine site on plasminogen and plasmin, preventing plasmin from binding to fibrin. Antifibrinolytic drugs are widely used, particularly in cardiac and orthopedic surgery, and previous reviews have found them to be effective in reducing blood loss, the need for transfusion, and even the number of reoperations for continued or recurrent bleeding.[47] The use of EACA in our institution has also shown a statistically lower intraoperative estimated blood loss, a total perioperative blood loss (including through the chest tube and Hemovac), and transfusion requirements. However, EACA has a manufacturer-reported risk of causing intracranial hypertension, although this has never been published in neurosurgical, cardiac, orthopedic, or general surgical literature after the intraoperative use of EACA.

All 3 patients in our current case series had been given EACA after anesthesia induction at 100 mg/kg over a period of 15 minutes (not to exceed 5 g), and then a maintenance dose of 10 mg/kg/hr was given until wound closure.[46–49] Our institution has extensive experience with EACA, as more than 1500 spinal deformity cases have been surgically treated since 1998, but there have been no neurological or other complications directly related to its use. Our experience includes a prospective preliminary study, a randomized double-blinded study, a fibrinogen study, and anterior and posterior spinal fusion studies, as well as a study on neuromuscular disorders.[13,47] However, the serum fibrinogen levels were found to be significantly elevated above normal in the initial 2 weeks after administration of aminocaproic acid.[46,47] Thompson et al.[46] had reported that the postoperative fibrinogen levels in the serum of 57 consecutive patients with idiopathic scoliosis increased gradually and substantially from Day 1 to Day 5 after surgery, despite stopping EACA at the end of surgery.

Notably, there is a reported case of intracranial hypertension in an infant with vertebral osteomyelitis with spinal canal stenosis and kyphosis, where the fibrinogen levels were remarkably elevated.[48] Considering the aforementioned reports, the underlying hyperfibrinogenemia cannot be disregarded as a probable mechanism for development of intracranial hypertension in patients with spinal deformity after surgical correction in which antifibrinolytic therapy has been used.

It is important that spine surgeons treating deformities be aware of the phenomenon of IIH as a cause of postoperative headache. The recommended medical treatment of IIH comprises acetazolamide 500 mg at bedtime for 3 days and then 500 mg twice daily up to 2–4 g per day if there are no contraindications.[4,40] Topiramate is another alternative in patients who are acetazolamide-intolerant. Lasix has been tried in some cases, but it has no proven benefit; steroids are generally avoided, except in acute visual loss.[4] This clinical disorder is distinct from the postoperative spinal headache that develops from intraoperative dural tear and resultant CSF leak, where the patient exhibits postural variation of headache and improvement with bed rest, hydration, and symptomatic treatment. Although there is no consensus view on either the cause or management of IIH, it is possible to reverse the visual impairment with timely medical intervention as in the reported cases.

Conclusions

We present the first case series of 3 patients who were diagnosed with postoperative IIH at a high-volume pediatric practice of spine deformity correction surgery. The cause of this extremely rare postoperative condition could be related to the structural venous outflow changes related to surgery and/or due to the hyperfibrinogenemia resulting from EACA for perioperative blood conservation. While this condition is a very uncommon occurrence after spinal surgery, we believe that if it is recognized early enough, it can be effectively treated with medication such that a long-term visual field loss can be prevented.

Disclosure

Dr. Thompson is a co-editor of the *Journal of Pediatric Orthopedics*. 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: Cohen, Kunes, Thompson, Poe-Kochert. Acquisition of data: all authors. Analysis and interpretation of data: all authors. Drafting the article: all authors. Critically revising the article: Cohen, Thompson, Manjila. Reviewed submitted version of manuscript: Cohen, Thompson, Manjila. Approved the final version of the manuscript on behalf of all authors: Cohen. Study supervision: Cohen, Thompson.

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Manuscript submitted June 15, 2011.
Accepted July 28, 2011.

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