Review article

Neurological risks in scheduled spinal surgery

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ABSTRACT

Spinal surgery is a high-risk specialty with an ever-increasing patient volume. Results are very largely favorable, but neurologic damage, the most severe complication, may leave major sequelae, some of which can be life-threatening. Neurologic complications may be classified according to onset (per- vs. postoperative) and surgical site (cervical vs. thoracolumbar). The present paper provides quantitative data for the risks involved. Knowledge of these complications and their risk of onset is the best means of guiding prevention strategies. The spine surgeon is part of a multidisciplinary team, with the radiologist and electrophysiologist, which is able to identify risk factors preoperatively and diagnose neurologic complications per- or postoperatively.

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Introduction

The number of patients undergoing spinal surgery is constantly increasing, for several reasons. On the supply side, the possibilities of care have grown with improvements in diagnostic techniques, imaging, methods of treatment, equipment and materials. Moreover, the media publicity given to these advances in spinal surgery has led to increased patient demand.

The increasing number and complexity of procedures increases the potential number of perioperative neurological complications. Onset may be at any stage of treatment, and complications may be classified by period of onset as well as by the underlying mechanism [1].

The present instructional course seeks to assess neurological risk in spinal surgery. Risk is inherent to any medical or surgical procedure. The surgeon must assess the risk/benefit ratio, which determines his or her responsibility. Orthopedic surgery is recognized by the public authorities, including the Health Authority, to be an “at-risk” specialty, and spinal surgery is one of the subspecialties with the highest rates of litigation. Spinal surgery is usually functional; the patient therefore needs clear information concerning the proposed procedure, including the risk of neurological complications. The risk/benefit ratio should be discussed with the patient, and informed consent obtained.

The surgeon should also be trained in risk prevention, which is part of the professional training program instituted under the French In-Service Development scheme (Développement Professionnel Continu [DPC]).

In a systematic review of the literature on complications in spinal surgery, Nasser et al. analyzed 105 articles. Of the 79,471 patients, 16.4% presented a complication of one type or another, and incidence was twice as high in thoracolumbar surgery (17.8%) as for the neck (8.9%) [2].

Neurological structures may be damaged via direct or indirect mechanisms. Direct causes comprise compression, traction, and laceration and avulsion. Indirect causes comprise ischemic phenomena induced by elongation or compression of medullary or radicular vascularization.

Neurological complications of spinal surgery may occur per- or postoperatively.

Perioperative complications

Patient installation

By precaution, positioning should be adapted to a much longer surgery time than planned. All possible compression and traction points on the face, trunk and limbs should be inventoried.

Ocular complications:

As well as corneal lesions, spinal surgery involves risk of neurological ophthalmic complications. Lesions may involve the occipital cortex, optic nerve or retinal nerve cells. Visual disorder or loss may complicate not only cervical but also thoracolumbar surgery. Incidence is increasing, although still very low; it is 10 times as great after surgery in prone position, but may also occur with lateral decubitus. The Scoliosis Research Society estimates the rate of ophthalmic lesions at 1%, with a 0.05–1% risk of loss of vision [3].
Neurologic ocular lesions. Neurologic ocular complications may take the form of ischemic optic neuropathy, central retinal artery occlusion or cortical central loss of vision.

Ischemic optic neuropathy (ION) mainly implicates spinal surgery in prone position. Onset may be perioperative, associated with arteritis or not. It may be bilateral but is more often unilateral (in 70% of cases), with immediate visual loss in 19% of cases [4]. This highlights the role of systemic factors, which almost always underlie unilateral loss of vision, more than mere malpositioning. Prognosis is very often unfavorable, with unilateral and sometimes bilateral visual disorder or even definitive visual loss. Identified risk factors comprise more than 41 blood loss, more than 4 hours’ hypotension, surgery time exceeding 7 hours and severe hypoxia.

Central retinal artery occlusion: resulting loss of vision is almost always irreversible. Occlusion follows direct compression of the eyeball. The resulting intraocular pressure comes to exceed intravascular pressure, causing arterial occlusion and irreversible retinal ischemia. More rarely, it may be due to an atheromatous embolus of carotid origin.

Cortical central loss of vision results from occipital lobe stroke and is usually bilateral. It is frequently due to embolism or hypoperfusion of the occipital cortex. Causes are very numerous, occurring in a context of cardiac arrest, prolonged shock or gaseous embolism. Rarer causes have been reported, including embolism during cervical osteotomy in a seated position [5]. Prognosis is favorable and most victims recover sight.

Prevention of ocular complications. The efficacy of treatments for visual disorders is low, whence the importance of prevention.

Positioning should be with the head raised, to minimize facial and periorbital edema. Eyeball compression must, obviously, be avoided. The surgeon should position the patient very carefully on a classical “horseshoe” headrest, preferably in foam, tailored to protect the eyes, nose and respiratory system; even better is the single-use Mayfield® headrest, with fixation by 3 skull pins, leaving the whole face and neck region entirely free and accessible throughout surgery.

A second important point is for the anesthesiology team to maintain stable hemodynamics. Finally, blood loss should be rapidly compensated during hemorrhagic procedures.

Neurologic compression of the limbs

Peripheral nerve lesions are among the most frequent perioperative complications [6]. Plexus and trunk lesions of the limbs are mainly due to malpositioning.

Brachial plexus elongation. Lesions of the brachial plexus occur in the axillary fossa between the first fixation on the cervical vertebrae and the second on the axillary fascia. It lies close to the clavicle, first rib and superior extremity of the humerus, which may all induce compression or elongation. As well as such purely mechanical phenomena, the brachial plexus may undergo a combination of mechanical and ischemic effects by hypoperfusion of the vasa nervorum. Prolonged hypovolemia and hypotension are also risk factors, aggravated by hypothermia [7] or comorbidities such as diabetes or alcoholism.

Any positioning may induce peripheral nervous damage, especially in the brachial plexus. The rate of neurologic lesions due to defective patient positioning is 0.14% for all procedures taken together [8], with brachial plexus involvement in 38% of these. Upper-limb abduction exceeding 90° in prone position causes traction and compression between the clavicle and first rib. In lateral decubitus, the brachial plexus is compressed if the shoulder is not released forward but placed between the thorax and the operating table. In supine position, excessive retropulsion creates tension in the brachial plexus, especially if shoulder abduction exceeds 90°. On awakening, patients complain of pain in the shoulder concerned, radiating into the supra-spinatus fossa. Motor and sensory impairment varies with the extent of elongation and compression and the length of surgery. Prognosis is usually favorable. Recovery takes several weeks to months and requires lengthy rehabilitation.

Truncal involvement. Nerve trunk involvement may affect all 4 limbs.

The ulnar nerve may suffer compression at the elbow, at the upper-limb pressure point. Median nerve involvement is rarer.

Peroneal nerve compression at the fibular neck is possible in any patient positioning, inducing simple paresthesia or severe motor impairment with drop foot.

Femoral cutaneous nerve involvement results in meralgia paresthetica following ventral decubitus with compression of the anterior superior iliac spine region. A prospective study reported 20% prevalence of femoral cutaneous nerve damage after spinal surgery [9]. In half of the patients, involvement was bilateral, secondary to compression of the framework supporting the anterior superior iliac spines. More rarely, there was neurological damage due to retroperitoneal hematoma or sustained during iliac crest graft harvesting. In 85% of cases, recovery was complete within 3 months [9].

Prevention of limb nerve-trunk lesions. Patient positioning is a key step and the responsibility of the surgeon. All possible compression and stretching points along the nerve trunks of the four limbs and brachial plexus should be checked. Each risk region should be palpated to ensure that it is free; if necessary, a protection should be fitted. The shoulders should not be unduly lowered in making the inferior cervical spine accessible, and any cervical traction should be moderate.

Neurologic risk according to surgical site

The approach to the spine and spinal contents obviously entails a risk of medullary and radicular lesion. This may occur with a direct approach to the vertebral canal, but also with the canal intact: there may be direct instrumental trauma, faulty implant positioning or faulty preparation of the implant site. Neurologic deficits may be induced by damage to peripheral neurologic or vascular structures within the approach.

Cervical spine

Medullary lesions. All anterior and posterior approaches incur a risk of medullary lesion; incidence is estimated at 0.2 to 0.9% [10]. The identified risk factors are myelopathy, medullary atrophy or ossification of the posterior longitudinal ligament. Correction of severe kyphosis with release and extensive fusion and also major instability are further risk factors.

Prevention of these severe complications requires good medullary perfusion maintained by arterial pressure > 80 mm Hg. Excessive cervical spine flexion or extension is to be avoided. Certain authors recommend monitoring evoked potentials on transcranial electrical stimulation. Hilibrand et al. reported that, in cervical spine surgery, evoked motor potentials on transcranial electrical stimulation showed sensitivity and specificity of 100%, compared to respectively 100% and 25% for evoked somesthetic potentials [11]. At end of surgery, before closing the approach, it is strongly recommended to make a final check on the osteosynthesis, and the position of the graft or interbody implant; this should also be done immediately in case of change in evoked potentials.

Radicular lesions. Reported incidence varies greatly, from 0.2 to 3.2%, due to differences in study populations. Disc surgery is associated with the lowest risk, while medullary decompression for...
myelopathy entails elevated risk. In the latter case, the C5 root is the most often affected, in 2.3 to 6.7% of cases, depending on the procedure [12-14]. The C5 root has a short sheath and may be subject to traction by medullary mobilization after decompression. Restored lordosis, spinal cord retraction, a C5 located in mid-lordosis and possible fixation in foraminal stenosis are all risk factors. The result is deltoid impairment, with recovery possibly lasting several months.

Cerebral lesions following vertebral artery trauma. The vertebral arteries, branching from the subclavian arteries, pass through a bony canal formed by the transverse process of the cervical vertebrae. They then skirt the lateral masses of the atlas and enter the cranium via the occipital passage. The mean distance between the unco-vertebral joint and transverse hole is 5.5 mm. Numerous anatomic variants, however, have been described, such as arterial loops with an enlarged vertebral artery hole. The risk of surgical trauma to the vertebral artery is estimated at 0.3% [15]. The risk of stroke following iatrogenic vertebral artery lesion is estimated at 3.8% on the left and 1.8% on the right [10], whence the need for angiography ahead of any arterial ligature or embolization. In case of vertebral artery lesion, a direct approach is possible by raising the longus colli muscle and opening the transverse canal. Vascular repair may be slightly postponed after packing, and be dealt with by a vascular surgeon. Nevertheless, embolization by interventional radiology is preferable.

Inferior laryngeal nerve lesion. The recurrent or inferior laryngeal nerve, a collateral branch of the pneumogastric nerve (Xth cranial pair), is the motor nerve of the larynx, and lesions induce dysphonia. The right recurrent nerve originates from X in the inferior part of the sternocleidomastoid region, and follows a concave route above, skirting forward and behind the inferior side of the right subclavian artery. On the left, it originates from X at the aortic cross, which it skirts before climbing along the left edge of the esophagus and then behind the thyroid lobe.

Estimates of the risk of dysphonia following cervical spine surgery on an anterior approach vary widely, from 2 to 30%; this is due to the criteria employed: dysphonia [16] or proven elective recurrent nerve lesion [17]. There is no consensus as to an approach that would minimize risk. A recent retrospective series of 418 patients found no significant difference between right and left approaches in terms of inferior laryngeal nerve lesion risk [18].

Sympathetic trunk lesions. The cervical sympathetic chain is located in the space between the posterior lateral pharyngeal and carotid regions. The cervical region comprises 3 ganglia. The superior ganglion is in C2-C3; the middle ganglion, adjacent to C6, is variable; and the stellate ganglion lies in the costo-transverso-pleural fossa. Damage to the sympathetic chain, and to the stellate ganglion in particular, induces Claude Bernard Horner syndrome, with an incidence of 0.2 to 4% [19]. It is usually revision surgery that is implicated. Evolution is generally favorable, but at an interval of several weeks. Prevention involves approaching the anterior cervical spine in the mid part, raising the medial edge of the longus colli muscle without excessive traction.

Thoracic and lumbar spine

The thoracic spinal cord is especially exposed, with poorer vasculization than in the cervical or upper lumbar cord. The spinal cord may suffer or experience severe ischaemia by arterial hypoperfusion, as reported in surgery for spinal deformity or extensive approaches.

Surgery for thoracic and lumbar spinal deformity. The risk of complete or partial paraplegia was 0.55% in a series of 1194 patients operated on for spinal deformity; this is much higher than for serious neurological impairment after fusion on a well-aligned spine (0.14%) or after lumbar discal surgery (0.03%) [20]. In the 2005 retrospective review by the Groupe d'Étude de la Scoliose, 1.78% of 3311 patients showed neurologic complications following scoliosis surgery, including 30 medullary lesions (4 Brown-SEQUARD lesions, 7 partial monoplegias and 18 complete paraplegias). Evolution was favorable for 19 patients, with full neurological recovery. Sixteen of the 24 radiologic lesions in the series showed full recovery [21]. The risk of medullary damage is especially high in posterior distraction correction of short kyphosis, wide-angle scoliosis, surgery for deformity secondary to congenital malformation or in case of pre-existing medullary lesion or neurologic deficit. These medullary lesions are of vascular origin, the mechanism being elongation during maneuvers of distraction or of correction by stem rotation. Clearly, direct trauma by a badly positioned screw or hook or onset of intracranial hematoma can cause medullary or radicular complications in such procedures. Preoperative whole-medulla MRI seeks to identify abnormalities of the medulla, from the cranio-cervical junction to the lower spine, which call for special vigilance regarding onset of these complications.

Correction by pedicular subtraction osteotomy (PSO). Correcting severe spinal balance disorder in the sagittal and/or frontal plane may require PSO. It is performed preferably in the lumbar region: for posterior subtraction, the lower the correction site, the greater the correction achieved; however, it must sometimes be thoracolumbar, thoracic or even cervical. This complex surgery may cause radicular or medullary lesions due to excessive stretching aside for the approach, or contusion or ischemia in neurologic structures, which may suffer damage at any point in the procedure, whether during bone resection or at closure of the osteotomy. Circumferential release of the dural sheath can also prove dangerous, especially in revision procedures. The risk of dural tear is increased, and repair is more difficult if this is on the anterior side of the sheath. The main complications are neurological, with transient or definitive deficit [22]. Buchowski et al. reported an 11.1% rate of deficit, 2.8% being permanent [23]. More recent series had fewer complications, and underlined the patients’ satisfaction [24].

Anterior surgery. Exposing vertebral bodies may require vascular ligature. This may damage the radiculomedullary spinal nutrient arteries, inducing severe ischemic neurologic deficit. The anterior medullary Adamkiewicz artery is usually located in T9 and on the left; there are, however, many variants, and the spinal cord is also vascularized by each metameric branch. Ischemia can be prevented by using unilateral ligature, performed in the convexity and remote from the foramen. Once again, peroperative hypotension is to be avoided, to prevent medullary artery perfusion deficit.

Corrective surgery for high-grade lumbar spondylolisthesis. Severe slippage is accompanied by turning on a transverse axis, with lumbar-sacral kyphosis. Reducing the slippage and local kyphosis entails neurologic risk, especially to the L5 root. According to the Scoliosis Research Society’s review of morbidity, neurologic involvement is the most frequent complication in this procedure, occurring in 11.8% of cases. Complementary osteotomy significantly increases the risk of such complications [25]. Prevention requires release up to the extra-foraminal region with constant surveillance while positioning implants and performing reduction maneuvers. Radicular deficit is mainly caused by stretching, which needs to be assessed by checking root tension, by the surgeon and/or electrophysiologically [26]. After reduction surgery, the patient should be positioned supine with hips and knees in flexion, to reduce sciatic nerve tension. Lower limb extension can
be resumed gradually, over a number of days if necessary, and depending on the patient's self-reported symptoms.

**Neurologic risk and spinal implants.** Whatever material is used (screws, hooks or interbody cages implanted via a posterior, transforamen, trans-psosas or anterior approach), the cord or roots may be damaged by poor positioning or per- or postoperative implant mobilization. Problems of positioning are especially serious in spinal deformity, and above all in dysplasia of the posterior arch or of a part of the spine. There is a rich literature on pedicular screwing in adults, with a consensus that the technique is safe, even in the thoracic region. The rate of malpositioning is quoted as 4.2%, but is found to be 15.7% on control CT. Nevertheless, the rate of major neurovascular complications in the literature is very low [27]. A systematic review by the Scoliosis Research Society and the Pediatric Orthopaedic Society of North America task force reported 91.5% good positioning of thoracic pedicular screws in scoliosis in adults and 94.9% in pediatrics. The low complication rates and significantly better efficacy of screwing as compared to the use of hooks or hybrid assemblies are sufficient for pedicular screws to be formally recommended [28].

**Sympathetic trunk and hypogastric plexus involvement.** Ejaculation is governed by sympathetic fibers coming from medullary centers T10-L2. The sympathetic ganglion chain follows the lateral side of the lumbar spine and continues behind the vena cava then in the inter-aorta-caval space on the right and laterally to the aorta on the left. The hypogastric plexus extends from the superior part of L4 to T1. Lesions to these fibers incur a risk of retrograde ejaculation. Approaching the L5S1 disc requires careful blunt dissection, to progressively push the hypogastric plexus fibers leftward. Coagulation should be bipolar, and as limited as possible. A retroperitoneal approach is much less risky for the hypogastric plexus than a transperitoneal approach [29]. The risk of hypogastric plexus damage during the approach for anterior interbody fusion ranges from 0.42 to 4.1% [29,30]. The sexual impact in women has not been thoroughly assessed, but includes vaginal dryness.

Exposing the superior part of the lumbar spine does not incur any risk of ejaculatory disorder, as the sympathetic fibers adhere to the large vessels. The sympathetic chain running along the anterior and medial edge of the psoas, on the other hand, risks trauma during the approach, with possible vasomotor disorder in the ipsilateral lower limb, characterized by edema and elevated local heat.

**Iatrogenic radicular lesions during lumbar surgery.** Radicular decompression associated to discl surgery or treatment of a narrow lumbar canal incurs a risk of neurological deficit or cauda equine syndrome. Excessive traction on the dural sac or on a root sheath before sufficient release has been achieved may induce ischemic damage. The incidence of peroperative radicular trauma is estimated at 0.4% [31].

**Postoperative complications**

**Epidural hematoma**

Onset of acute lumbar pain raises a suspicion of postoperative hematoma. Such lumbar pain is the forerunner of neurological sensory or motor deficit or of cauda equine syndrome. Clinical assessment by complete neurological examination, including perineal examination, is mandatory. In case of neurological deterioration, emergency CT or MRI should be performed. When epidural hematoma is diagnosed on examination of the surgical site and in light of the context, emergency surgical evacuation may in some cases be necessary, without waiting for imaging so as not to delay decompression of neurological structures and to maximize the chances of recovery.

Compressive epidural hematoma is a result of bleeding, usually in the epidural venous network or in sectioned cancellous bone, or else of defective drainage. The risk is estimated at less than 1% [32]. Risk factors are: tumor surgery, antiplatelet and anticoagulant treatment, coagulation disorder, disorders secondary to inadequate compensation of severe bleeding, and reduced drainage due to a dural tear.

**Dural tear**

The incidence of accidental durotomy during thoracolumbar surgery is estimated at 5.1%. McMahon et al. reported a 7.7% rate of neurological complications with dural tear, versus 1.5% without. The risk of dural tear is three-fold higher in revision surgery [33]. Peroperative repair is mandatory. Careful suturing may if necessary be backed up by a muscle fascia patch or interposition of a muscle or fat graft, fibrin or glue. Postoperative drainage after dural tear is controversial; some authors recommend non-aspirative or supraaponeurotic drainage after hermetic closure of the various planes [34]. Dural leakage may induce cerebral hemorrhagic complications such as intracerebellar hemorrhage, or subdural or extradural hematoma. Intradural hypotension leads to traction on the epidural veins and bleeding. Any central neurological effect or unusual headache is an alarm signal: emergency cerebral imaging is mandatory [35].

**Risk prevention**

Optimal risk prevention involves awareness of these multiple complications, to be ensured during surgical training and by communication of information to practicing surgeons.

The very severe consequences of these neurological complications mandate the utmost rigor at all stages of surgery.

**Preoperative prevention**

Each patient should have a recent clinical examination, the results of which should be compared with those of imaging to ensure concordance. Indications should conform to published guidelines. Surgical planning includes checking imaging data and the absence of anatomic particularities such as transitional abnormality, vertebral abnormality or intramedullary or radicular abnormality. The surgeon should check the ready availability of all the material needed for the approach and the instrumentation, and then check the patient’s positioning: head straight, or slight flexion of the cervical spine in case of suspected narrow canal, with the face and eyeballs free (Mayfield® headrest recommended in long surgery), and absence of compression points on the limbs and abdomen to avoid increased blood loss.

**Peroperative prevention**

Medullary or radicular decompression surgery requires a complete instrument set, including Kerrisson forceps of various sizes and also lengths. This allows surgery to be adapted to the shape of the canal and the depth of the operative site. The aim is to have the heel of the instrument parallel to the dura mater, with no aggression by the tip or the heel.

A motorized burr may be useful, with irrigation if possible to avoid overheating or filling of the burr and to improve visualization. “Diamond” burrs are preferable, being less aggressive toward soft tissue and reducing the risk of neurologic laceration.

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Pedicle screwing involves a learning curve and requires good knowledge of entry-point landmarks. Screws may be placed freehand or under peroperative fluoroscopic control. Peroperative frontal and lateral controls are essential in superior cervical spine osteotomy, to limit the risk of neurovascular lesions.

Peroperative intracranial bleeding should be dealt with by moderate bipolar coagulation. Bleeding may also be controlled by swabbing with hemostatic gel or, temporarily, by hemostatic compresses (Surgicel®).

**Surveillance of peroperative evoked potentials**

Peroperative electrophysiological surveillance has greatly enhanced neurologic safety in surgery for spinal deformity. However, monitoring evoked somesthetic potentials (ESP) alone is insufficient. Efficacy requires multimodal monitoring, associating ESP to evoked motor potentials (EMP) by transcranial stimulation. Evoked neuromotor potentials (ENMP) are less effective than ESP. Feng et al. reported respectively 91.7% and 98.8% sensitivity and specificity for changes in EMP, versus respectively 50% and 95.2% for ESP. Associating the two raises sensitivity to 92.9% and specificity to 99.4%. Vertebral osteotomy, correction of a curve with a Cobb angle exceeding 90° and severe preoperative kyphosis correlated with elevated risk of change on peroperative electrophysiological monitoring [36].

Indications for use of EMP by transcranial stimulation, ESP and sometimes continuous EMG should be extended to high-risk interventions such as cervical spondylotic myelopathy surgery or reduction of high-grade spondylolisthesis.

**Recommendations for spinal anesthesia**

One cause of medullary insult is ischemia by hypoperfusion. The anesthesia team should ensure arterial blood pressure, compensate or prevent blood loss and combat hypothermia.

In case of electrophysiological monitoring, the anesthesia protocol needs to be adapted, to maintain body temperature, avoiding curarization if EMPs by transcranial stimulation are to be studied.

**Immediate postoperative monitoring**

Neurological examination on awakening is mandatory and should be repeated in the recovery room and on the following days. Findings should be entered in the patient’s file.

Standardized surveillance by non‑medical care staff complements the vigilance of the surgeon, who should be alerted in case of any change in sensory or motor parameters. Any manifest complication requires immediate surgical revision, without waiting for imaging examinations.

**Conclusion**

Spinal surgery provides good functional and anatomic results. However, it exposes patients to a variety of risks, some neurologic. Risk awareness implies implementing prevention strategies at every stage of treatment, pre-, peri- and postoperative. Rigor in indications and technique minimizes neurological risk. The contribution of new imaging and electrophysiology tools is to be assessed on a case-by-case basis.

**Disclosure of interest**

The author declares that he has no conflicts of interest concerning this article.

**References**


