

# Risk Factors, Assessments, and Treatment of Intra- and Postoperative New Neurologic Deficits in Complex Spine Disorders

**Hongqi Zhang**

Department of Spine Surgery and Orthopaedics, Xiangya Hospital, Central South University, Changsha

**Lige Xiao**

Department of Spine Surgery and Orthopaedics, Xiangya Hospital, Central South University, Changsha

**Mingxing Tang**

Department of Spine Surgery and Orthopaedics, Xiangya Hospital, Central South University, Changsha

**Yang Sun**

Department of Spine Surgery and Orthopaedics, Xiangya Hospital, Central South University, Changsha

**Guanteng Yang** (✉ [ygtspine@163.com](mailto:ygtspine@163.com))

Department of Spine Surgery and Orthopaedics, Xiangya Hospital, Central South University, Changsha

---

## Research Article

**Keywords:** New neurologic deficits, Complex spine disorders, Early management, Conservative treatment, Revision surgery

**Posted Date:** July 28th, 2021

**DOI:** <https://doi.org/10.21203/rs.3.rs-744638/v1>

**License:**  This work is licensed under a Creative Commons Attribution 4.0 International License. [Read Full License](#)

---

# Abstract

**Background:** New Neurologic Deficits (NND) is one of the most threatening complications of spinal surgery, and its incidence in complex spine disorders ranges from 0.99% to 3.54%, which is higher than that in noncomplex spine disorders. To date, the early management of NNDs in complex spine disorders remains poorly researched.

**Methods.** A retrospective review was performed for patients with complex spine disorders who experienced NNDs from 2010 to 2020. The pre- and postoperative neurologic condition was assessed using the American Spinal Injury Association (ASIA) scale. Patient age, sex, diagnosis, lesion level, operating time, blood loss, intraoperative neurophysiologic monitoring (IONM) test results, wake-up test results, lowest mean arterial pressure (MAP) at surgery, NND types, possible etiology of NNDs, treatment, and total recovery time were reviewed retrospectively.

**Results:** Five patients with complex spine disorders who experienced NNDs were included (4 males and 1 female; average age of  $23\pm 17$  years) in the present study. The primary diseases varied from congenital scoliosis to Langerhans histiocytosis. The mean operation time was  $488\pm 264$  min with a mean blood loss of  $1920\pm 1413$  mL, and the mean lowest MAP at surgery was  $66.2\pm 7.6$  mmHg. Regarding the type of NND, 4 cases had spinal cord injuries, and 1 case had nerve root injury. The possible etiologies of NNDs in the patients were as follows: spinal cord overtraction and spinal cord ischemia in 2 cases; spinal cord compression and spinal cord ischemia in 2 cases; and spinal cord ischemia 1 case. Two patients underwent revision surgery, and 1 patient underwent prolonged surgery. The average hospital stay was  $37\pm 11$  days. The preoperative ASIA score was  $4.4\pm 0.8$ , while the postoperative ASIA score was  $0.8\pm 0.7$ . All patients achieved full recovery at a mean follow-up period of  $6.8\pm 4.5$  months.

**Conclusion:** Surgeries for complex spine disorders carry significant risks that can lead to intraoperative or postoperative NNDs. NNDs can occur secondary to spinal cord overtraction (overcorrection of deformity), spinal cord compression (due to implants, bone tissue, soft tissue, or hematoma), and spinal cord ischemia (owing to anemia, low MAP, vascular embolism, or intramedullary vascular malformation). Patients with risk factors should be closely observed during and after the operation. Once NNDs are confirmed, emergency examination should be performed to rule out spinal cord overtraction and spinal cord compression. If a mechanical obstruction is found, emergency revision surgery is recommended. If no mass lesion is identified, conservative treatment should be utilized for the principle of maintaining arterial pressure, nutrating nerves, dilating blood vessels, and eliminating edema.

## Background

Many complications can occur with spinal surgery. Despite the best of care, all surgical procedures have potential risks of complications, and even well-experienced surgeons cannot avoid all complications. Among all perioperative complications associated with spinal surgery, intra- and postoperative neurologic deficits are the most concerning complications[1–4]. It has been reported that patients with a primary diagnosis of complex spinal disorders, such as scoliosis, kyphosis, and primary tumors, have a higher rate of new neurologic deficit (NND) rates than patients with other noncomplex spinal disorders, such as fractures, degenerative disease, and adult spondylolisthesis[5].

In the surgical treatment of complex spinal disorders, NNDs ranging from nerve root to spinal cord involvement may result from several mechanisms as follows: 1) direct injury from surgical instruments due to complex deformities; 2) compressive injury due to soft or bony tissue removal or correction of spinal deformity; 3) vascular compromise owing to thrombus or ischemia; and 4) spinal cord ischemia-reperfusion injury. The outcomes of NNDs range from complete recovery to partial recovery to no recovery. To decrease the rates of NNDs resulting from complex spine disorders, intraoperative assessments of neurological function, including the wake-up test and later IONM, have been adopted. However, the data supporting their use are insufficient, and controversy remains regarding if and when such monitoring results should be assessed as positive results[6–9].

Although the incidence of NNDs is relatively higher in complex spine disorders than in other spinal surgeries, its overall rate is low in all intra- and postoperative complications, ranging from 0.99–3.54%[5]. To date, the early management of NNDs in complex spine disorders remains poorly researched. Most research regarding NNDs are case reports. By reviewing the complex spine disorder cases with new neurologic deficits in our center, we aimed to describe the risk factors, to discuss the possible etiological mechanisms behind this complication, and to suggest strategies for its management.

## Methods

A total of 5 complex spine disorder patients with new neurologic deficits between 2010 and 2020 were included in the present study. The pre- and postoperative neurologic conditions were assessed using the ASIA scale. Patient age, sex, diagnosis, lesion level, operating time, blood loss, IONM test results, wake-up test results, lowest MAP at surgery (mmHg), NND types, primary disease, following treatment, and total recovery time were examined retrospectively.

## Results

### Major clinical data

Five patients (4 males and 1 female; average age at the time of surgery was 23 years, ranging from 11–57 years) underwent spinal surgery in our center. The primary disease was congenital scoliosis in 1 patient, neurofibroma-1 scoliosis in 1 patient, Chiari 1 scoliosis in 1 patient, Langerhans histiocytosis with incomplete paraplegia in 1 patient, and ankylosing spondylitis with kyphosis and a history of cervical and thoracolumbar spine surgery in 1 patient. The mean operation time was  $488\pm 264$  min with a mean blood loss of  $1920\pm 1413$  ml, and the mean lowest MAP at surgery was  $66.2\pm 7.6$  mmHg (Table 1). The types of NNDs were spinal cord injury in 4 cases and nerve root injury in 1 case. The potential causes of NNDs were as follows: spinal cord overtraction and spinal cord ischemia in 2 cases; spinal cord compression and spinal cord ischemia in 2 cases; and spinal cord ischemia in 1 case. Two patients underwent revision surgery, and 1 patient underwent prolonged surgery. The average hospital stay was  $37\pm 11$  days, and the average ASIA score was  $4.4\pm 0.8$  preoperatively and  $0.8\pm 0.7$  postoperatively. All patients reached full recovery at a mean of  $6.8\pm 4.5$  months (Table 2).

### Assessment and treatment of NND for each case

#### *Case No. 1*

A 14-year-old male diagnosed with congenital scoliosis presented C7 and T6 hemivertebrae and T1-5 vertebral segmental insufficiency. Radiological assessments showed that the lateral convex angle of the cervicothoracic segment was  $49^\circ$  and that kyphosis angle of the cervical kyphosis was  $37^\circ$ , and the difference in shoulder height was 21 mm. The bending film showed that the flexibility of the cervicothoracic curve was 4%, and the compensation ability of the lower cervical and middle thoracic segments was poor. After assessment, the patient underwent combined anterior and posterior surgery. First, the patient was placed in a supine position with continuous traction of the cranial arch after anesthesia, and we then resected the C7 hemivertebra using titanium mesh and internal plates for fixation. Second, posterior correction was performed with continuous traction of the cranial arch. After internal fixation, we first resected the T6 hemivertebra and closed the residual cavity of the hemivertebra using a temporary titanium rod. When the residual cavity of the hemivertebrae was closed by posterior correction, IONM showed that the amplitude of evoked potential in motor evoked potential (MEP) and somatosensory evoked potential (SEP) was low, but no spinal cord compression was found during spinal canal exploration. The operative time was 450 min with a blood loss of 1200 ml, and the lowest MAP at surgery was 68 mmHg. The postoperative muscle strength of the patient was as follows: grade 1 in the left upper limb; grade 3 in the right upper limb; grade 1 in the left lower limb; and grade 3 in the right lower limb. The postoperative muscle tension was normal. Emergency CT failed to demonstrate any spine compression or spinal cord overtraction;

therefore, spinal cord ischemia was considered the main cause of the NNDs. The patient was immediately treated with high-dose methylprednisolone (30 mg/kg bolus followed by 5.4 mg/kg/hr for 23 hours). Adequate fluid infusion was given to obtain a minimum mean arterial pressure of 100 mm Hg. Neurotrophic therapy, blood vessel dilation treatment, and hyperbaric oxygen therapy (HPOT) were also provided. After 5 days of intensive medical management, the patient's muscle strength showed a significant recovery in muscle strength as follows: grade 3 in the left upper limb; grade 4 in the right upper limb; grade 3 in the left lower limb; and grade 4 in the right lower limb. After 3 months of follow-up, the muscle strength of this patient recovered to normal.

#### *Case No. 2*

A 22-year-old male was diagnosed with neuromuscular scoliosis. X-rays showed cervical kyphosis with a kyphosis angle of 80°. MRI showed mild compression in front of the spinal cord. The patient underwent halo gravity traction (max traction weight of 5 kg) for 3 weeks, and the kyphosis angle decreased to 45 degrees. Afterwards, the patient underwent one-stage posterior correction. IONM showed that the amplitude of evoked potentials in the MEP and SEP was low. Postoperatively, the patient's right shoulder joint was unable to abduct with a muscle strength of grade 1 in the right deltoid muscle. However, postoperative X-ray and CT showed that the correction of kyphosis was satisfactory. No sign of internal fixation displacement, compression, or hematoma was observed. Similar to the first case, the patient showed no recovery after 1 week of medical treatment. Hence, we planned a reoperation to decrease the correction of kyphosis and to enlarge the intervertebral foramen on the right side of C4-5. The muscle strength of the right deltoid recovered to grade 2 after the operation and returned to normal 1 month later. The 3 month follow-up showed that the kyphosis angle decreased to 9°.

#### *Case No. 3*

A 12-year-old male was diagnosed with Chiari's malformation and scoliosis. Preoperative X-ray showed that the Cobb angle was 80° with a flexibility of 24%, and preoperative MRI showed cerebellar tonsillar hernia and syringomyelia. The patient underwent posterior internal fixation and scoliosis correction surgery. During operation, IONM reported that the MEP disappeared and that the SEP distinctly weakened. The wake-up test showed that the lower limb activity disappeared, while the upper limb activity was normal. Hence, we decided to remove the internal fixation and explore the nerves to ensure that there was no nerve entrapment. After exploration, no nerve entrapment was found. Considering these findings, we elected to use in situ fixation for safety. However, no improvement in SEP, MEP, or wake-up test was observed. Thus, we removed the fixation again and opened the T6-T10 lamina to expose the spinal cord and found that the corresponding spinal cord on the concave side of T6-T10 was compressed by the spine canal. Pedicle resection and laminectomy were performed on the concave side of T6-T10, and spinal cord adduction surgery was performed to remove the spinal cord from the concave side to the convex side. Immediately after we finished the spinal cord adduction surgery, a recovery in the signal of the MEP and SEP was observed albeit weak, but it gradually recovered with time. One day after the operation, the patient's low limb muscle strength recovered to grade 3. At the 3 month follow-up, the patient showed a total recovery. Successful radiographic fusion was confirmed with CT reconstruction, and the final follow-up X-ray showed that the Cobb angle was 28°(fig 1).

#### *Case No. 4*

An 11-year-old female was diagnosed with thoracic vertebral destruction and intraspinal abscess at the T4 level. The low limb muscle strength before the operation was grade 3. The patient underwent posterior approach decompression, debridement, and internal fixation. Due to the decompression of the spinal cord by the tumor, there was a significant reduction in the amplitude of the SEP and MEP in the lower limbs, especially on the right side. After removing the tumor, the amplitude of the SEP and MEP of both lower limbs was unsatisfactory. The postoperative lower limb muscle strength was grade 0, and incontinence of stool and urine was observed. Emergency CT scan showed no sign of compression. Similar to the first case, urine function began to recover 3 days after the operation after medical treatment.

Seven days after the operation, stool function began to recover, and the left lower limb strength gradually recovered. Seventeen days after the operation, the right lower limb strength gradually recovered. Five months later, the muscle strength of the lower limb returned to grade 4. The 1 year follow-up showed that the muscle strength returned to normal. The patient was diagnosed with Langerhans cell syndrome by postoperative pathology and thus received chemotherapy. There was no recurrence to date.

#### *Case No. 5*

A 57-year-old male was diagnosed with ankylosing spondylitis with kyphosis deformity and low limb muscle strength before operation grade 4. The patient had a history of trauma and surgery. The patient had C6 spondylolysis and a T12 fracture due to an accident and underwent open reduction and internal fixation of cervical and thoracic vertebrae 3 years ago. During the operation, the T11-12 left screw rod fixation was removed, and severe scar adhesion was found in the spinal canal during decompression. During the procedure, the amplitude of the SEP and MEP decreased. Postoperative physical examination showed dyskinesia of the lower extremities, grade 1 lower extremity muscle strength, and hypoesthesia of both lower extremities. Because there was no signal of internal displacement or spinal cord compression, conservative treatment was adopted. Similar to the first case, the patients' neurological function gradually recovered. Before he was discharged from the hospital, the lower extremity muscle strength recovered to grade 3. At the 3 month follow-up, the lower extremity muscle strength recovered to grade 4. A total recovery was observed at the 1 year follow-up. Full radiographic fusion was confirmed with CT reconstruction.

## **Discussion**

New neurological deficits (NNDs) following surgical correction of complex spinal disorders are rare. Bridwell et al.[10] reported a large series of 1090 patients with complex spinal disorders undergoing surgery, in which only 4 patients (0.36%) developed NNDs. The possible causes for NNDs were classified as spinal ischemia in 3 of the 4 cases as well as vascular and mechanical problems in 1 case. After conservative treatment, all patients showed marked improvement. MacEwen et al.[11] reviewed 7885 scoliosis patients who underwent surgery, and they reported that 57 patients (0.72%) developed NNDs for complete and incomplete paraplegia. Among these patients, only 36% achieved a complete recovery, while 32% achieved partial recovery. Other similar studies have reported a rate of NNDs ranging from 0.3–0.6%. More recently, Hamilton et al.[5] reported data from the Scoliosis Research Society Morbidity and Mortality Committee (SRS M&M) on NNDs in 2010. According to the report, the NND rate in patients with a primary diagnosis of scoliosis or kyphosis ranges from 0.99–3.54%, and the complete recovery rate is between 37.5% and 55.6%. The inconsistency in the incidence and recovery rate of NNDs in each study may be related to the inclusion and exclusion criteria as well as the skill of surgeons and the overall medical level. Although the incidence is low, NNDs remain one of the most feared complications of spinal surgery. To prevent NNDs or select an appropriate treatment for NNDs, an in-depth understanding of their etiology and risk factors is needed.

#### **Risk factors for NNDs in complex spine disorders**

Complex spinal diseases are generally related to a complex surgical procedure, increased surgical fusion segment, osteotomy, orthopedics, and stripping of the adherent tissue, such as a tumor or postoperative scar on the spinal cord. At the same time, the increase in operation complexity also indicates extension of operation time, increase in blood loss, decrease in MAP, and low O<sub>2</sub> saturation, which may also increase the incidence of NNDs[12–16]. In the present study, a longer operation time (488 ± 264 min), an increase in blood loss of 1920 ± 1413 ml, and a lower MAP at surgery (66.2 ± 7.6 mmHg) were observed. In addition, anatomical features result in a higher incidence rate of cervical and thoracic segments (especially T2-T4), and intraspinal abnormalities, such as vascular malformation, syringomyelia, and intraspinal space-occupying lesion, also have a potential risk of NNDs[15, 17–22]. In the present study, 3 cases underwent orthopedic and osteotomy surgery, and 1 case with a history of cervical and thoracolumbar surgery underwent orthopedic surgery,

osteotomy surgery, and stripping of the postoperative scar from the spinal cord. Moreover, 1 case underwent stripping of the tumor tissue from the spinal cord. All 5 cases were located at the cervical to thoracic level. All patients underwent fusion and implant surgery with a mean fusion level of  $7.8 \pm 3.48$ . Similar to our study, the survey based on 108,419 spine surgeries in the SRS M&M database reported that features likely reflective of increased case complexity, such as primary diagnosis of spondylolisthesis scoliosis or kyphosis, and procedures, such as revision, fusion, and use of implants, have increased rates of NNDs[5].

### Etiologies of NNDs in complex spine disorders

The exact etiology of NNDs remains unknown but is likely multifactorial. There are 3 major potential causes of NND as follows: spinal cord compression, spinal cord overdistraction, and spinal cord ischemia. In the present, 2 patients had spinal cord compression with spinal cord ischemia, 2 patients had spinal cord distraction with spinal cord ischemia, and 1 patient had spinal cord ischemia.

### Requirement of reoperation with the occurrence of NNDs

When NND occurs during or after surgery, it is necessary to exclude mechanical obstruction in the spinal canal caused by internal implants, hematoma, and bony tissue. In addition, excessive traction and shrinkage of the spinal cord also need to be ruled out. If mechanical obstruction is found, emergency revision surgery is needed. With physical compression eliminated, no progressive aggravation of NNDs is presented, and the possibility of spinal cord ischemia, postoperative hypotension, and/or anemia should be considered[23, 24]. The options include induced hypertension, prednisone pulse therapy, and nutritional nerve therapy. Revision surgery for partial correction release is also recommended when conservative treatment provides no sign of recovery. In the present study when conservative treatment showed no sign of improvement, 2 patients had partial correction release during surgery, and 1 patient had partial correction release 1 week after surgery. Two patients underwent conservative treatment because there was no sign of mechanical obstruction.

### Reduction of the incidence of NNDs

The measures can be taken to minimize NNDs: 1) accurate screw placement, firm fixation, moderate orthopedic angle, and no excessive pursuit of orthopedic angle; 2) for severe rigid scoliosis and/or spinal cord deformity, preoperative traction can reduce the incidence of NNDs [25, 26]; 3) during the operation, the vertebral venous plexus should be destroyed as little as possible to stop bleeding thoroughly and prevent the formation of hematoma; 4) IONM and intraoperative wake-up test should be used during operation; 5) aggressive perioperative volume repletion should be performed to maintain mean arterial pressure with the mean arterial pressure maintained above 65 mm Hg during operation and approximately 100 mmHg postoperation [14]; 6) conservative treatment should include high-dose methylprednisolone (30 mg/kg bolus followed by 5.4 mg/kg/hr for 23 hours), neurotrophic therapy, blood vessel dilation treatment, and HPOT.

## Conclusion

Surgeries for complex spine disorders carry significant risks that can lead to intraoperative or postoperative NNDs. NNDs can occur secondary to spinal cord overtraction (overcorrection of deformity), spinal cord compression (due to implants, bone tissue, soft tissue, or hematoma), and spinal cord ischemia (owing to anemia, low MAP, vascular embolism, or intramedullary vascular malformation). Patients with risk factors should be closely observed during and after the operation. Once a NND is confirmed, emergency measures should be taken to rule out spinal cord overdistraction and spinal cord compression. If a mechanical obstruction is found, we recommend emergency revision surgery. If no mass lesion is identified, conservative treatments should be utilized for the principle of maintaining arterial pressure, nerve nutrition, blood vessel dilation, and edema elimination.

## Abbreviations

NND: New Neurologic Deficits; ASIA: American Spinal Injury Association; IONM: intraoperative neurophysiologic monitoring; MAP: mean arterial pressure; MEP: motor evoked potential; SEP: somatosensory evoked potential; HPOT: hyperbaric oxygen therapy; SRS M&M: Scoliosis Research Society Morbidity and Mortality Committee

## Declarations

### Ethics approval and consent to participate

Our research was approved by the ethics department of Xiangya Hospital, Central South University, Changsha, China. We have consensus with all participants. We also followed the Declaration of Helsinki and relevant policies in China.

### Consent for publication

Written informed consent was acquired from each of the patients or their parents and legal guardians to authorize treatment, imageology findings, and photographic documentation. The patients or their parents and legal guardians consented to the publication of their pictures as well as their anonymous and clustered data.

### Availability of data and material

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

### Competing interests

The authors declare that they have no competing interests.

### Funding

This study was supported by the National Natural Science Foundation of Hunan (2019JJ80014, 2020JJ5919). No benefit in any form has been or will be received from a commercial party related directly or indirectly to the subject of this manuscript.

### Authors' contributions

HZ designed the study. LX, MT and YS performed the data collection, statistical analysis and data interpretation. GY contributed to manuscript writing. GY and LX contributed to patient enrollment and follow-up. All authors read and approved the final manuscript.

### Acknowledgements

The authors thank all the staff of the Department of Spine Surgery, Xiangya Hospital, Central South University for their dedicated assistance in patient sample collection.

## References

1. Delank, K.S., H.W. Delank, D.P. Konig, et al., *Iatrogenic paraplegia in spinal surgery*. Arch Orthop Trauma Surg, 2005. **125**(1): p. 33–41.
2. Gok, B., D.M. Sciubba, G.S. McLoughlin, et al., *Revision surgery for cervical spondylotic myelopathy: surgical results and outcome*. Neurosurgery, 2008. **63**(2): p. 292-8; discussion 298.
3. Mohamad, F., S. Parent, J. Pawelek, et al., *Perioperative complications after surgical correction in neuromuscular scoliosis*. J Pediatr Orthop, 2007. **27**(4): p. 392–7.

4. Diab, M., A.R. Smith, T.R. Kuklo, et al., *Neural complications in the surgical treatment of adolescent idiopathic scoliosis*. Spine (Phila Pa 1976), 2007. **32**(24): p. 2759–63.
5. Hamilton, D.K., J.S. Smith, C.A. Sansur, et al., *Rates of new neurological deficit associated with spine surgery based on 108,419 procedures: a report of the scoliosis research society morbidity and mortality committee*. Spine (Phila Pa 1976), 2011. **36**(15): p. 1218–28.
6. Lieberman, J.A., R. Lyon, J. Feiner, et al., *The efficacy of motor evoked potentials in fixed sagittal imbalance deformity correction surgery*. Spine (Phila Pa 1976), 2008. **33**(13): p. E414-24.
7. Bindal, R.K. and S. Ghosh, *Intraoperative electromyography monitoring in minimally invasive transforaminal lumbar interbody fusion*. J Neurosurg Spine, 2007. **6**(2): p. 126–32.
8. Wang, S., Y. Yang, Q. Li, et al., *High-Risk Surgical Maneuvers for Impending True-Positive Intraoperative Neurologic Monitoring Alerts: Experience in 3139 Consecutive Spine Surgeries*. World Neurosurg, 2018. **115**: p. e738-e747.
9. Wu, Y. and A. Vazquez-Barquero, *Stimulus-Evoked Electromyographic Monitoring During Minimally Invasive Transpedicular Implantation of Screws in Lumbosacral Spine: Threshold Value, Methodology and Clinical Effectiveness*. World Neurosurg, 2017. **98**: p. 146–151.
10. Bridwell, K.H., L.G. Lenke, C. Baldus, et al., *Major intraoperative neurologic deficits in pediatric and adult spinal deformity patients. Incidence and etiology at one institution*. Spine (Phila Pa 1976), 1998. **23**(3): p. 324–31.
11. MacEwen, G.D., W.P. Bunnell, and K. Sriram, *Acute neurological complications in the treatment of scoliosis. A report of the Scoliosis Research Society*. J Bone Joint Surg Am, 1975. **57**(3): p. 404–8.
12. Qiao, J., L. Xiao, X. Sun, et al., *Vertebral subluxation during three-column osteotomy in surgical correction of adult spine deformity: incidence, risk factors, and complications*. Eur Spine J, 2018. **27**(3): p. 630–635.
13. Muralidharan, A., W. Shoap, K. Al Robaidi, et al., *Postoperative Neurological Complications Following Revision Spine Surgery: A State Inpatient Database Analysis*. Int J Spine Surg, 2020. **14**(4): p. 607–614.
14. Keyoung, H.M., A.S. Kanter, and P.V. Mummaneni, *Delayed-onset neurological deficit following correction of severe thoracic kyphotic deformity*. J Neurosurg Spine, 2008. **8**(1): p. 74–9.
15. Qiu, Y., S. Wang, B. Wang, et al., *Incidence and risk factors of neurological deficits of surgical correction for scoliosis: analysis of 1373 cases at one Chinese institution*. Spine (Phila Pa 1976), 2008. **33**(5): p. 519–26.
16. Dharmavaram, S., W.S. Jellish, R.P. Nockels, et al., *Effect of prone positioning systems on hemodynamic and cardiac function during lumbar spine surgery: an echocardiographic study*. Spine (Phila Pa 1976), 2006. **31**(12): p. 1388–93; discussion 1394.
17. Zhang, H.J., N. Silva, E. Solli, et al., *Treatment options and long-term outcomes in pediatric spinal cord vascular malformations: a case report and review of the literature*. Childs Nerv Syst, 2020. **36**(12): p. 3147–3152.
18. Zhang, H.Q., Y.X. Wang, C.F. Guo, et al., *Minimum 5-year follow-up outcomes for one-stage posterior instrumentation without neurosurgery intervention for correction of scoliosis associated with Chiari I malformation and syringomyelia*. Arch Orthop Trauma Surg, 2020.
19. Tan, H., Y. Lin, T. Rong, et al., *Surgical Scoliosis Correction in Chiari-I Malformation with Syringomyelia Versus Idiopathic Syringomyelia*. J Bone Joint Surg Am, 2020. **102**(16): p. 1405–1415.
20. Dang, L., Z. Liu, X. Liu, et al., *Sagittal en bloc resection of primary tumors in the thoracic and lumbar spine: feasibility, safety and outcome*. Sci Rep, 2020. **10**(1): p. 9108.
21. Tong, C.K., J.C. Chen, and D.D. Cochrane, *Spinal cord infarction remote from maximal compression in a patient with Morquio syndrome*. J Neurosurg Pediatr, 2012. **9**(6): p. 608–12.
22. Novy, J., *Spinal cord syndromes*. Front Neurol Neurosci, 2012. **30**: p. 195–8.
23. Dapunt, U.A., J.M. Mok, M.S. Sharkey, et al., *Delayed presentation of tetraparesis following posterior thoracolumbar spinal fusion and instrumentation for adolescent idiopathic scoliosis*. Spine (Phila Pa 1976), 2009. **34**(25): p. E936-

41.

24. Auerbach, J.D., K. Kean, A.H. Milby, et al., *Delayed Postoperative Neurologic Deficits in Spinal Deformity Surgery*. Spine (Phila Pa 1976), 2016. **41**(3): p. E131-8.
25. Zhang, H., G. Yang, C. Guo, et al., *Analysis of the corrective contribution of strong halo-femoral traction in the treatment of severe rigid nonidiopathic scoliosis*. J Orthop Surg Res, 2020. **15**(1): p. 567.
26. Zhang, H.Q., A. Deng, C.F. Guo, et al., *Posterior-only surgical correction with heavy halo-femoral traction for the treatment of extremely severe and rigid adolescent idiopathic scoliosis (> 130 degrees)*. Arch Orthop Trauma Surg, 2021.

## Tables

TABLE 1. General information surgical Indications, and Operations Performed for complex spine disorders patients with NND

Cases	Gender	Age	Indication	Operation	Fusion level	Operation Time(min)	Operation Blood Loss(ml)	Lowest MAP at surgery(mmHg)
1	M	14	C6, T7 hemivertebra and T1-5 incomplete segmentation	Anterior cervical hemivertebra resection and posterior thoracic hemivertebra resection and scoliosis correction	Anterior☒ C6-T1 Posterior☒ C5-T9	450	1200	68
2	M	22	Cervical kyphosis with neurofibroma-1	Posterior cervical kyphosis correction	Posterior☒ C2-7	300	500	75
3	M	12	Charis 1 malformation with scoliosis and Syringomyelia	Posterior scoliosis correction	Posterior☒ T3-L4	1000	4000	73
4	F	11	Langerhans histiocytosis with incomplete paraplegia	Posterior tumor resection and internal fixation	Posterior☒ T2-6	270	700	60
5	M	57	Ankylosing spondylitis with kyphosis and history of cervical and thoracolumbar spine surgery	Osteotomy for ankylosing spondylitis	Posterior☒ T9-L3	420	3200	55

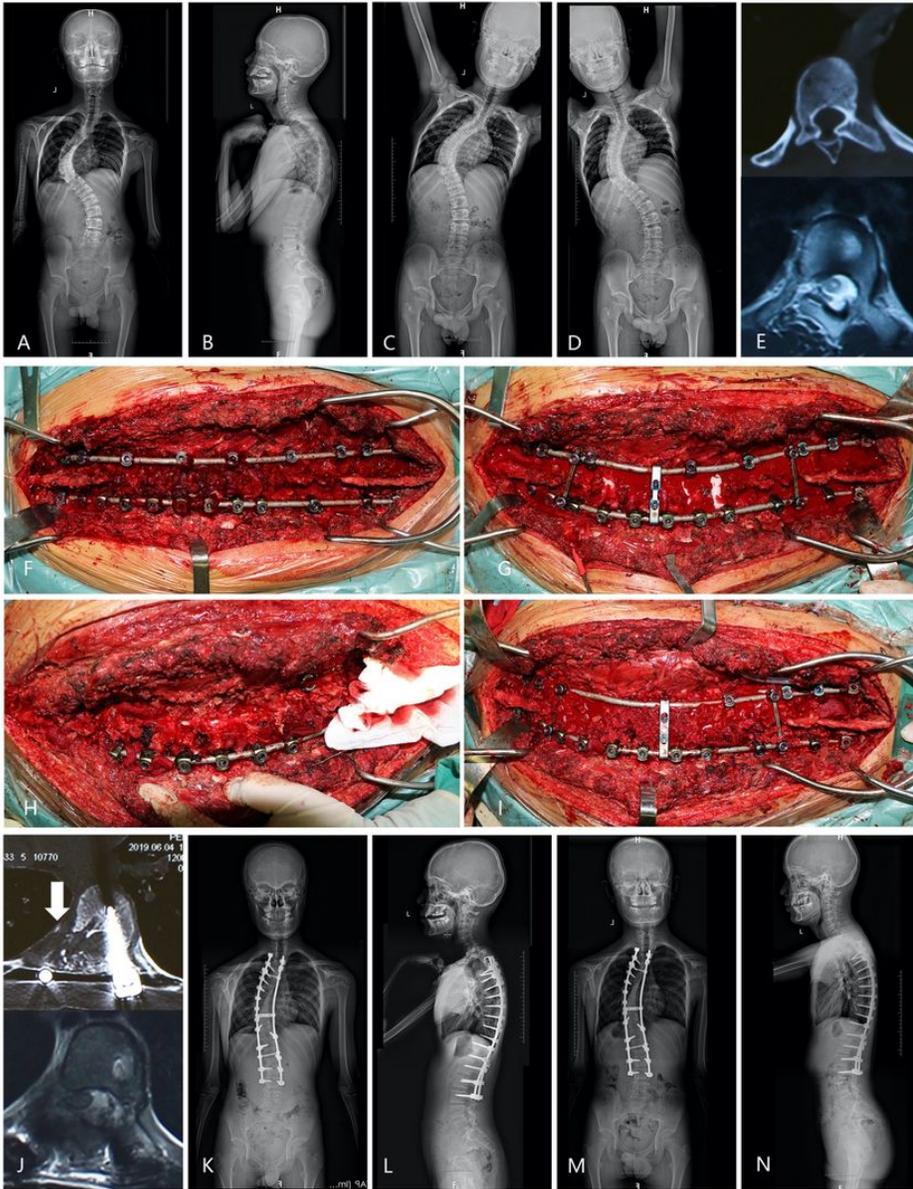
Abbreviation: NND, New Neurologic Deficits

TABLE 2. Types, possible etiology, treatment, and outcomes of NND for Patients with complex spine disorders

Cases	Types of NND	Possible etiology	Treatment	Hospital stays	Neurologic Grade Pre-OP	Neurologic Grade post-OP	Neurologic Grade back to normal(mouth)
1	Spinal cord injury	Spinal cord ischemia	active conservative treatment	47	5	1	5(3)
2	Nerve root injury	Spinal cord over distraction and spinal cord ischemia: Excessive correction of kyphosis	Revision surgery to release part of correction	51	5	0	5(1)
3	Spinal cord injury	Spinal cord compression and spinal cord ischemia: concave side of apical vertebra compressed the spinal cord	Pedicle resection and Spinal cord transposition	28	5	2	5(6)
4	Spinal cord injury	Spinal cord over distraction and spinal cord ischemia: stripping the tumor off the spinal cord.	active conservative treatment	37	3	0	5(12)
5	Spinal cord injury	Spinal cord compression and spinal cord ischemia: Excessive correction of kyphosis	release part of correction and active conservative treatment	22	4	1	5(12)

Abbreviations: NND, New Neurologic Deficits Pre-OP, preoperation post-OP, postpreoperation

## Figures



**Figure 1**

Typical cases (case 3) A 12-year-old male was diagnosed Chiari's malformation and scoliosis. Preoperative X-ray showed that the Cobb angle was 80° with the flexibility of 24%, preoperative MRI showed syringomyelia, and the spinal cord leans to the concave side of the pedicle(A-E). After the first orthopedic surgery, the IONM and wake-up test indicating that the lower limb activity disappeared(F). hence, we performed a revision surgery and use in situ fixation for safety, however, no apparent improvement has been seen after surgery(G). Thus, we removed the fixation again and opened the T6-T10 lamina to expose the spinal cord, and found that the corresponding spinal cord on the concave side of T6-T10 was compressed by the spine canal. Pedicle resection and laminectomy were performed on the concave side of T6-T10, and spinal cord adduction surgery was performed to remove the spinal cord from the concave side to the convex side (H-J). At the 3-month follow-up, the patient showed a total recovery(K-L). and the final follow-up X-ray showed that the Cobb angle was 28° (M-N).