Nerve root anomalies: implications for transforaminal lumbar interbody fusion surgery and a review of the Neidre and Macnab classification system

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Lumbar nerve root anomalies are uncommon phenomena that must be recognized to avoid neural injury during surgery. The authors describe 2 cases of nerve root anomalies encountered during mini-open transforaminal lumbar interbody fusion (TLIF) surgery. One anomaly was a confluent variant not previously classified; the authors suggest that this variant be reflected in an amendment to the Neidre and Macnab classification system. They also propose strategies for identifying these anomalies and avoiding injury to anomalous nerve roots during TLIF surgery. Case 1 involved a 68-year-old woman with a 2-year history of neurogenic claudication. An MR image demonstrated L4–5 stenosis and spondylolisthesis and an L-4 nerve root that appeared unusually low in the neural foramen. During a mini-open TLIF procedure, a nerve root anomaly was seen. Six months after surgery this patient was free of neurogenic claudication. Two years after surgery, this patient was free of radicular pain. Case 2 involved a 60-year-old woman with a 1-year history of left L-4 radicular pain. Both MR and CT images demonstrated severe left L-4 foraminal stenosis and focal scoliosis. Before surgery, a nerve root anomaly was not detected, but during a unilateral mini-open TLIF procedure, a confluent nerve root was identified. The unique challenges presented by nerve root anomalies can make standard procedures more complicated and can increase the risk for iatrogenic injury. Therefore, preoperative diagnosis and identification of nerve root anomalies is important and helps the surgeon plan a safer surgical approach. However, even MRI, which has been shown to provide the resolution necessary to successfully classify anomalies, can fail to detect small anastomotic branches between nerve roots. Thus, when preoperative imaging fails to detect a nerve root anomaly, intraoperative detection is imperative if nerve root injury is to be avoided.

Key Words • anomaly • confluent nerve root • fusion • transforaminal • transforaminal lumbar interbody fusion

Abbreviation used in this paper: TLIF = transforaminal lumbar interbody fusion.

Spinal nerve root anomalies are well-described but uncommon phenomena that must be recognized to avoid inadvertent nerve injury during surgery. Previous studies have determined that the incidence of these anomalies varies: 1.3% when found during surgery, 2.0%–6.7% when found by imaging before surgery, and 14.0% when found during cadaver dissection. Several classification systems describe the different morphological appearances of these anomalies, including the Postacchini system, the Kadish and Simmons system, and the Neidre and Macnab system. The system developed by Neidre and Macnab is the most frequently cited for lumbosacral nerve root classification. It divides anomalies into 3 types: conjoined, redundant, and anastomatic. Of these, conjoined nerve roots are by far the most common, followed by anastomatic anomalies.

Because of the larger cross-sectional area of anomalous nerve roots and a tethering effect from the contributing branches, patients with these anomalies might be more susceptible to radicular symptoms and often require aggressive decompressive surgery to maximize the chances of a good clinical outcome. The unique challenges presented by nerve root anomalies can make standard procedures more complicated and can increase the risk for iatrogenic injury. Therefore, preoperative diagnosis and identification of nerve root anomalies is important and helps the surgeon plan a safer surgical approach. However, even MRI, which has been shown to provide the resolution necessary to successfully classify anomalies, can fail to detect small anastomotic branches between nerve roots. Thus, when preoperative imaging fails to detect a nerve root anomaly, intraoperative detection is imperative if nerve root injury is to be avoided.

Some of the commonly treated degenerative conditions that co-occur with nerve root anomalies include recurrent disc herniation, spinal/foraminal stenosis, and spondylolisthesis. One operation that is used to treat these conditions is TLIF.
Anomalies are frequently not identified on preoperative images, injury to an unrecognized anomalous nerve root can easily occur during lumbosacral decompression and fusion operations.\textsuperscript{1,9,14,15,20,23,24,29,33,34,36} Therefore, spine surgeons should be adequately prepared to identify these congenital variations during surgery.

To our knowledge, only 2 articles in the English-language literature describe nerve root anomalies of any form encountered during TLIF procedures.\textsuperscript{6,30} However, neither article clearly addresses strategies to both identify these anomalies and avoid injuring the nerves during TLIF. Among 200 TLIFs performed by our senior author (R.I.R.), 2 cases of nerve root anomalies were encountered; this incidence is consistent with the reported incidence of these anomalies.\textsuperscript{36} Our objectives are to describe these 2 cases of nerve root anomalies encountered during TLIF; to add a new category (describing an unclassified variant) to the Neidre and Macnab classification system, and to propose an appropriate course of action for identifying and preserving anomalous nerve roots encountered during TLIF procedures.

**Case Reports**

**Case 1**

**History and Examination.** The patient was a 68-year-old woman with a 2-year history of neurogenic claudication involving both lower extremities. Medications and 2 epidural steroid injections provided no benefit. Examination revealed 4+/5 strength in her right quadriceps and anterior tibialis muscles. An MR image (Fig. 1) demonstrated L4–5 stenosis and spondylolisthesis. While reviewing the MR image, we noted that the right L-4 nerve root seemed to be unusually low in the neural foramen. On a parasagittal view, the right L-4 nerve root also seemed to show a common trunk with the L-5 nerve root. Therefore, before surgery, the patient was thought to most likely harbor a Type 1B Neidre and Macnab anomaly.

**Operation.** The patient had right L-4 nerve root compression as well as spinal stenosis. Therefore, we recommended decompression and TLIF with the caveat that an interbody graft might not be possible, given the abnormally low location of the L-4 nerve root in the right L4–5 foramen. The surgical approach was a right mini-open Wiltse approach. Intraoperatively, while performing the L4–5 laminectomy and right facetectomy, the surgeon (R.I.R.) noted almost complete absence of the ligamentum flavum (Video 1).

**Video 1.** Clip showing surgery for Case 1. Click here to view with Media Player. Click here to view with Quicktime.

After the facetectomy was performed, the L-4 nerve root appeared to be unusually low in the foramen and was found to emerge from a common trunk with the L-5 nerve root (Fig. 2, Video 1), as had been observed on preoperative images. The L-4 nerve root traveled just rostral to the L-5 pedicle, and the L-5 nerve root traveled just caudal to the L-5 pedicle. Given that the L-4 nerve root was directly over the L4–5 disc space, interbody fusion was not possible. Therefore, right L4–5 pedicle screws and rod were placed. An additional small Wiltse incision was made on the left side, allowing placement of the L4–5 pedicle screw and rod.

**Postoperative Course.** Six months after surgery, the patient reported resolution of her neurogenic claudication. Postoperative radiographs are shown in Fig. 3.

**Fig. 1.** Case 1. MR images showing L4–5 central stenosis and spondylolisthesis. A: Midline sagittal T2-weighted image demonstrating Grade 1 L4–5 spondylolisthesis and nonsymptomatic L5–S1 spondylolisthesis. B: Axial T2-weighted image showing right L4–5 foraminal stenosis. C: Right parasagittal T2-weighted image demonstrating a low-lying right L-4 nerve root (arrow). D: Right parasagittal T2-weighted image demonstrating a common trunk (arrows) from which both the L-4 and L-5 nerve roots emanate. Dynamic movement of the image (not shown) enabled tracking of the L-4 and L-5 nerve roots into 1 common nerve root sleeve.

**Fig. 2.** Case 1. Intraoperative image showing the conjoined nerve root. Left is caudal and right is rostral. The conjoined nerve root is labeled L4-L5*. The L-4 nerve root travels just rostral to the L-5 pedicle, and the L-5 nerve root travels just caudal to the L-5 pedicle. The dura and L-5 pedicle are noted for orientation.

**Fig. 3.** Postoperative radiographs. A: Anteroposterior x-ray showing L4–5 interbody fusion. B: Lateral x-ray showing L4–5 interbody fusion.
Case 2

History and Examination. The patient was a 60-year-old woman with a 1-year history of left lower-extremity radicular pain in an L-4 distribution. Three epidural steroid injections had provided no lasting benefit. Examination revealed that she had left L-4 radicular pain and Grade 4+/5 strength in her left quadriceps and anterior tibialis muscles. An MR image (Fig. 4) demonstrated severe left L-4 foraminal stenosis. A CT image indicated focal scoliosis contributing to the foraminal stenosis. A nerve root anomaly was not detected on preoperative images.

Operation. Unilateral TLIF surgery was performed through a left mini-open Wiltse incision. After removal of the left L4–5 facet joint, the L-4 nerve root seemed tethered caudally and was unusually difficult to mobilize. Therefore, the area just rostral to the L-5 pedicle, which is typically a safe zone, was explored. An additional, smaller L-4 nerve root that branched off the thecal sac was observed over the L4–5 disc space (Fig. 5, Video 2).

Video 2. Clip showing surgery for Case 2. Click here to view with Media Player. Click here to view with Quicktime.

The larger, more rostral L-4 root and the smaller, caudal L-4 root branched off the thecal sac and joined to form a confluent root distally. After the anatomy was properly identified, the two L-4 nerve roots were mobilized rostrally, allowing placement of an interbody graft.

Postoperative Course. The operation was completed without complication. Two years after surgery, the patient was free of radicular pain. Postoperative radiographs are shown (Fig. 3).

Discussion

The 2 cases described here highlight the unique challenges that nerve root anomalies present during TLIF surgery. Although the morphologic appearance of the anomaly encountered in Case 1 is well described by the Neidre and Macnab classification system, the anomaly encountered in Case 2 is not described by this system. Therefore, we first review the 3 categories currently described by Neidre and Macnab, and then we propose a fourth class of confluent nerve roots that adequately describes the anomaly encountered in Case 2. We then discuss identification and surgical management of these anomalies during TLIF surgery.

Neidre and Macnab Classification

Type 1. Type 1 anomalies are conjoined nerve roots...
and are the most common anomaly reported in the literature. According to the Neidre and Macnab classification system, all conjoined roots eventually divide and exit via separate foramina. Conjoined nerve roots are further subdivided into those that arise from a common dural sheath (Type 1A) and those that have origins very close together on the thecal sac but do not share a common dural sheath (Type 1B) (Fig. 6). The anomaly encountered in Case 1 was a Type 1B anomaly.

Type 2. Type 2 anomalies involve redundant or “twinned” nerve roots, a situation in which 2 nerve roots exit through 1 intervertebral foramen. Type 2 nerve roots are further subdivided according to the presence of an extra root. If an extra nerve root is not present, the twinning in the intervertebral foramen will leave 1 foramen with no nerve roots passing through it (Type 2A). If an extra nerve root is present, it occupies the would-be empty foramen so that all the foramina are occupied (Type 2B) (Fig. 6).

Proposed Type 4. Our proposed Type 4 anomaly is a confluent nerve root anomaly, as observed in Case 2. In this patient, a normal-caliber L-4 nerve root exited the thecal sac caudal to the L-4 pedicle. Another, smaller L-4 nerve root exited the thecal sac caudal to the normal-caliber L-4 root. These 2 roots joined distally to form a confluent L-4 root that exited the L4–5 neural foramen (Fig. 7). To clarify, a confluent nerve root anomaly consists of 2 nerve roots that arise separately from the thecal sac and join together distally. This anomaly differs from a conjoined nerve root anomaly, in which 2 nerve roots arise from a common dural sheath and separate distally.

To our knowledge, a confluent nerve root anomaly was first described by Keon-Cohen in 1968 but was not included in the Neidre and Macnab classification system. Keon-Cohen described nerve root fibers emerging from the L-5 spinal level that joined with fibers emerging from the S-1 spinal level. The joined fibers formed a confluent nerve root, which then further branched distally. Since Keon-Cohen’s original description, 1 case of a cervical confluent root has been reported, but our literature search did not find another case of a lumbosacral confluent nerve root anomaly. Despite the apparent rarity of confluent nerve roots, it is still important for surgeons to be aware of this variant in the event it is encountered during surgery. Therefore, we propose adding this as a Type 4 variant in the current Neidre and Macnab classification system.

Management of Nerve Root Anomalies During TLIF

Satisfactory bone removal is an important part of the TLIF procedure. Removal of the entire facet joint with completion of pedicle-to-pedicle decompression creates a large working space, or safety zone, lateral to the thecal sac and between the exiting nerve root and the caudal pedicle. In patients with normal anatomy, working...
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Within this safety zone minimizes the risk for injury to the thecal sac or to the exiting nerve root during discectomy and placement of the interbody graft. However, as our experience demonstrates, patients with nerve root anomalies are at risk for neural injury during TLIF if the safety zone is not clear of anomalous roots. Thus, it is important to use a foraminal dissection technique that enables nerve root anomalies to be recognized before injuries occur.

To minimize the likelihood of neural injury and to identify any occult nerve root anomalies intraoperatively, we adhere to the following technique during all TLIF surgeries. First, as mentioned, we perform a complete facetectomy to create a large working area. This can be done in several ways, and our method can be seen in Video 1. Additional bone is removed until there is complete pedicle-to-pedicle decompression. We then remove ligamentum flavum until we are able to identify the lateral border of the thecal sac. Then, to identify the caudal aspect of the disc in the typical safety zone, we always start foraminally and just rostral to the caudal pedicle. We then identify the exiting nerve root, paying close attention to the axilla of the nerve root. Next we explore the tissue between the axilla of the nerve root and the previously identified caudal disc. A nerve root anomaly, if present, would most likely be identified within this tissue. Typically, however, this area consists only of epidural veins, which we coagulate and cut, to allow ample visualization of the entire disc space. At this time, it is safe to proceed with discectomy and placing the interbody graft.

There are 3 more clues that should alert the surgeon to look closely for a nerve root anomaly during the operation: 1) an atypical location of a nerve root, as in Case 1, in which the L-4 nerve root exited just rostral to the L-5 pedicle instead of just caudal to the L-4 pedicle; 2) a nerve root that exits the thecal sac at an atypical angle; and 3) difficulty mobilizing a nerve root despite satisfactory pedicle-to-pedicle decompression, as in Case 2. Other authors who have identified nerve root anomalies during surgery have confirmed that these intraoperative findings are diagnostic.

An additional clue, although not confirmed by other authors, might be the absence of normal ligamentum flavum, as seen in Case 1. In some instances of nerve root anomalies, placing an interbody graft is not possible. There are multiple ways to address this situation. First, one must decide whether increasing the height of the intervertebral foramen is necessary to alleviate the patient’s symptoms. If so, this can be addressed by performing a contralateral facetectomy and placing an interbody graft on the contralateral side. One can also consider distracting the pedicle screws away from each other during rod placement to further open the foramen. This procedure may be suboptimal, however, because distraction is a kyphogenic maneuver. If increasing the height of the intervertebral foramen is not necessary, one could consider using a bilateral pedicle screw construct without an interbody graft.

Conclusions

Nerve root anomalies present unique surgical challenges and can increase the risk for iatrogenic nerve injury. It is important to use a foraminal dissection technique that enables recognition of nerve root anomalies before the nerves are iatrogenically injured. Of the 2 cases presented here, 1 patient had a nerve root anomaly not previously classified: a confluent variant. We propose that this variant be classified as a Neidre and Macnab Type 4 anomaly.

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. Concept and design: Riesenburger, Burke, Safain. Acquisition of data: Riesenburger, Burke, Safain. Analysis and interpretation of data: all authors. Drafting the article: all authors. Critically revising the article: Riesenburger, Burke, Safain. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Riesenburger. Study supervision: Riesenburger.
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