Intraoperative Measurements of Nerve Root Tension During Posterior Lumbar Interbody Fusion

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Research Article

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Abstract

Background

There is no effective standard method to evaluate whether the nerve root tension is restored, which is an important indicator for the recovery of nerve function. This study aimed to demonstrate a technique for measuring nerve root tension during surgery.

Methods

A total of 54 consecutive patients (average age, 52.3 years; range, 28-68 years) received posterior lumbar interbody fusion for lumbar disc herniation comprised the patient sample.The nerve root tension was measured twice before and after intraoperative decompression by the nerve root tension meter modified from the transverse gauge by author. Clinical outcome was assessed by the visual analog scale (VAS) for leg pain, provided by patients before and after surgery.

Results

There was a significant improvement in the VAS score for leg pain after surgery compared with that before surgery (7.0 ± 2.24 vs. 0.8 ± 0.84, respectively; $P < 0.01$). Nerve root tension was significantly decreased after decompression compared with that before surgery (1.32 ± 0.22 N vs. 0.64 ± 0.17 N, respectively; $P < 0.01$). The nerve root tension was positively correlated with the VAS score ($r = 0.772$, $P < 0.05$; $r = 0.715$, $P < 0.05$).

Conclusions

This study shows that the nerve root tension meter can instantly and non-invasively measure nerve root tension during an operation. It was demonstrated that the nerve root tension of the patient is significantly reduced after decompression. Meanwhile, the VAS score improved significantly, and the nerve root tension and VAS scores were positively correlated.

Background

Lumbar radiculopathy is commonly caused by lumbar disc herniation (LDH) and the patients usually present with sciatica[1]. Its pathogenic mechanisms mainly include (1) Mechanical compression, (2). immune inflammation, and (3) stimulation of neurobiochemical substances. However, during the operation, the dural sac and nerve roots could be pulled dorsolaterally and the axial tension is high, which indicate that the pain radiating from the lower limb of patients with LDH is caused by the lumbar vertebral nerve roots that are mechanically squeezed to increase their own tension, thereby triggering a series of ischemic/hypoxic reactions. This may explain why some patients have large intervertebral disc herniation, shown on imaging, but experience very mild symptoms of pain in the lower back and leg. Because the lumbar vertebral nerve roots become relatively low and loose under physiological conditions, they are highly ductile and more able to withstand the traction forces caused by mechanical squeezing in patients. A lumbar discectomy, at present, only involves the removal of the physical compression of the nerve root. However, there is no effective standard method to evaluate whether the nerve root tension is restored, which is an important indicator for the recovery of nerve function. If the nerve root tension can be measured during surgery, it can not only effectively predict the prognosis of patients but also guide the surgeon to select the intervertebral fusion cage with the appropriate height to avoid iatrogenic traction injury and severe complications such as foot drop[2–5].

This study aimed to explore the feasibility of intraoperative nerve root tension measurement and to determine the correlation between nerve root tension and pain radiating from the lower extremities in patients.

Materials And Methods

Patient Group

Between June 2020 and August 2021, a total of 54 consecutive patients received posterior lumbar interbody fusion (PLIF) for LDH at Shanghai Ninth People's Hospital. Among them, there were 33 patients with L4/5 disc herniation and 21 with L5/S1 disc herniation. Inclusion criteria were as follows: (1) Simple lumbar disc herniation was not associated with lumbar spinal canal stenosis, lumbar spondylolisthesis, and other lumbar diseases; (2) leg pain was associated with large LDH; and (3) failure of conservative treatment over a 3-month period.

The average age of the patients at the time of surgery was 52.3 years, ranging from 28 to 68 years. There were 36 males and 18 females.

Surgical Procedure

All patients underwent PLIF. The patients were treated under general anesthesia in the prone position. After exposure of the dorsal spine at the stenotic level using a standard midline approach, the paraspinal muscles were subperiosteally elevated from the dorsal surface of the spinous process as far as the lateral border of the facet joints. The midline spinous processes, supraspinal and interspinous ligaments, as well as the majority of the lamina were left intact. The decompression was extended to the lateral recess. The transferring nerve roots were well protected using a probe. The nerve root tension was measured before decompression. The posterior longitudinal ligament was incised, the nucleus pulposus tissue was completely removed, and an interbody fusion cage, of appropriate size, was implanted. The pedicle screw system used was EXP (Depuy, America). The pedicle entry point was lateral, at the basis of the transverse process. All screws were inserted under direct vision using a medial angulation appropriate to the spinal level. The pedicle screws were connected with a rod and axially compressed. Before closure, each nerve root was checked to verify adequate decompression and the nerve root tension was measured again. The wound was closed in layers. A deep drain was applied and maintained for a mean duration of 2 days.

Intraoperative Nerve Root Tension Test

The nerve root tension meter used in this study was modified from the transverse gauge by author. A nerve hook was installed at the end of the force rod (Fig. 1). The instrument had two pointers (force and memory pointers). The surgeon can accurately read the dial count after pulling the nerve root through the nerve hook to cause effective displacement during intraoperative L5S1 nerve root exposure (Fig. 2).

In this study, nerve root tension was measured twice, before and after intraoperative decompression, and the changes in tension were observed. In order to reduce the measurement error, each measurement was performed three times and take the average value as the final data for statistical analysis.

Clinical Outcome Evaluation

Clinical outcome was assessed using the visual analog scale (VAS) for leg pain, provided by patients before and after surgery.

Statistical Analysis

Statistical analyses were performed using SPSS 11.0 for Windows. Experimental data are presented as mean ± SD. The Student's *t*-test was used for the comparison of continuous variables. Linear regression was used to analyze the correlation between the nerve root tension and the VAS. Results were considered statistically significant when the P-value was <0.05.

Results

The results are summarized in Table 1. There was a significant improvement in the VAS score for leg pain after surgery compared with that before surgery (7.0 ± 2.24 vs. 0.8 ± 0.84, respectively; P < 0.01). Nerve root tension significantly decreased after decompression compared with that before surgery (1.32 ± 0.22 N vs. 0.64 ± 0.17 N, respectively; P < 0.01). The nerve root tension was positively correlated with the VAS score (r = 0.772, P < 0.05; r = 0.715, P < 0.05). In this study, no patient had complications after surgery, such as foot drop.

Discussion

Lumbar radiculopathy is characterized by chronic pain that occurs in the lower back and legs. Early and correct diagnosis is essential. Magnetic resonance imaging is currently the most effective method for diagnosing lumbar radiculopathy[6–8]. However, some patients who have large intervertebral disc herniation, according to imaging, have very mild symptoms of pain in the lower back leg. Therefore, González Espinosa de Los Monteros et al.[9] proposed to check the patient's nerve root status by measuring their neurodynamic or orthopedic tension. The results of the slump test and Dejerine's triad test combined with straight leg test and Bragard test in multiple parallel manners showed the highest diagnostic accuracy and validity. The essence of the aforementioned study is to induce pain or paresthesia, by increasing tension in the nerve root, and determine the incidence of lumbar radiculopathy. This concept is consistent with the theoretical basis of our study: The diagnosis of lumbar radiculopathy should be based on the tension of the nerve root, rather than completely based on imaging technology.

Professor Shi[10] proposed that the pathological basis of lumbosacral nerve bowstring disease is nerve root or axial traction injury. However, most cases of this disease have no positive imaging findings. Furthermore, the results were consistent with those of our study that lumbar radiculopathy is caused by increased tension in the nerve root.

Some studies had demonstrated that the pathogenesis of lumbar radiculopathy is the nerve root axial traction injury. The spinal cord and its nerve roots showed rubber-like elasticity[11–13]. Singh et al.[11] found that the nerve root is elongated and the cross-sectional area is reduced when a nerve root is statically or dynamically pulled.

Electrophysiological monitoring found that the nerve conduction velocity and potential amplitude gradually decreased and the comprehensive action potential area became smaller or even disappeared, which eventually led to complete blockade of nerve root conduction.

Along with the increase in nerve root tension[12], stretching tension can not only directly lead to abnormal nerve conduction but also reduce blood flow in nerve roots and cause nerve ischemia-reperfusion (I/R) injury. Lin et al.[13] found that when radiation pain occurred in a straight leg elevation test, the blood flow was reduced by more than 70% in the L5/S1 nerve roots.

Because there is only a thin outer membrane around the nerve root, the nerve root is prone to mechanical injuries and its degree of damage is also high. The resistance to traction only accounts for 10% of the peripheral nerve[14–15]. In addition, the dorsal root ganglion cells, located on the dorsal side of the nerve root, are not only vulnerable to various inflammatory factors, which causes a series of hypoxia-ischemia reactions, but are also more vulnerable to mechanical injury[16–18]. Our results also confirmed that after decompression, the nerve root tension of the patient was significantly reduced, while the VAS score was also significantly improved; these changes were positively correlated with one another.

Methods that protect the nerve roots and avoid excessive traction during surgery have been the main concerns for many surgeons. To date, several studies have reported on nerve root blood flow[13, 19, 20], but only a few studies have reported on the mechanical tension in nerve roots because, from an ethical point of view, it is almost impossible to perform such invasive measurements in patients. Only human specimens or in vivo animal models can be used to measure the tension in the spinal nerve roots[11].

Recently, a surgical simulation system was developed, which involves a virtual reality simulator combined with real anatomical structures composed of synthetic materials. An inexperienced doctor can simulate the surgical operation through this system and record the nerve root damage during surgery[21]. However, the tension value of the nerve root cannot be immediately obtained during surgery, in order to guide the surgeon how to decompress properly and expand the intervertebral space, of appropriate height, to achieve the best results.

Our device for measuring nerve root tension is modified from a transverse gauge. A nerve hook is installed at the end of the force rod and the tension value is obtained by effective displacement of the nerve root when it is pulled by the nerve hook. The process is the same as with the normal intraoperative traction of the nerve root to expose the intervertebral space, but the degree of traction is much smaller than that of the normal operation. Therefore, it is safer for the nerve root and will not cause additional injury. The surgeon can judge whether the decompression is complete by comparing changes in nerve root tension before and after decompression. When the surgeon installs the intervertebral fusion cage and measures the tension again, a significantly increased tension will indicate that the cage height is too large and needs adjustment.

We consider that the loss of nerve root contractures and elasticity is in parallel with spinal degeneration and loss of intervertebral space height in elderly patients. With traditional lumbar spine surgery, the risk of iatrogenic nerve root injury is very high if the nerve root was in the axial direction.

Previous studies have shown that the nerve root traction injury caused by excessive expansion of the intervertebral space during surgery and the excessive use of the intervertebral fusion cage will cause nerve root I/R injury, postoperative pain and numbness in the lower limb, and relatively severe complications of foot drop[4, 22]. Professor Shi Jiangang[23] proposed the three heights (anatomical, natural, and pathological) idea of intervertebral disc. The size of the intervertebral fusion cage is appropriate to restore the natural height of the intervertebral space to maintain the optimal tension of the spinal nerve root, which is the “nerve standard” for spinal decompression. Our study on measuring intraoperative nerve root tension aimed to provide an accurate basis for this standard. The hand-held nerve root tension meter used in this study belongs to the first-generation product, which still has some shortcomings, including measurement error caused by unstable control of the tester during the measurement process. Nevertheless, to the best of our knowledge, no similar study has been reported to date. The method described in our study enables, for the first time, the immediate and non-invasive measurement of nerve root tension during surgery, which provides a new clinical direction.

In future studies, we will focus on improving the accuracy of the measuring instrument. Meanwhile, this study highlighted that more spine surgeons should pay attention to the nerve root tension and not be satisfied with physical compression of nerve roots and excessively pursue the restoration of the anatomical height of intervertebral space.

Conclusions

This study shows that the nerve root tension meter can instantly and non-invasively measure nerve root tension during an operation. It was demonstrated that the nerve root tension of the patient is significantly reduced after decompression. Meanwhile, the VAS score improved significantly, and the nerve root tension and VAS scores were positively correlated.

Abbreviations

VAS: visual analog scale

LDH: lumbar disc herniation

PLIF: posterior lumbar interbody fusion

I/R: ischemia-reperfusion

Declarations

Availability of data and materials

All data generated or analyzed during this study are included in this published article.

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Ethics declarations

Ethics approval and consent to participate

The study protocol was approved by by the Ethical Committee of the Shanghai Jiao Tong University School of Medicine. Informed consent was provided by all participating individuals.

Consent for publication

Not applicable.

Competing interests Statement

No competing interests.

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Tables

Table 1. Clinical outcome scores and nerve root tension before and after surgery

	Preoperative	Postoperative	P
VAS leg pain	7.0 ± 2.24	0.8 ± 0.84	<0.01*
Nerve root tension	1.32 ± 0.22 N	0.64 ± 0.17 N	<0.01*
Correlation between VAS and nerve root tension	r = 0.772, P < 0.05*	r = 0.715, P < 0.05*	
Values represent mean ± standard error. *Denotes statistically significant values.			

Figures

Figure 1

The nerve root tension meter used in this study was modified from the transverse gauge.

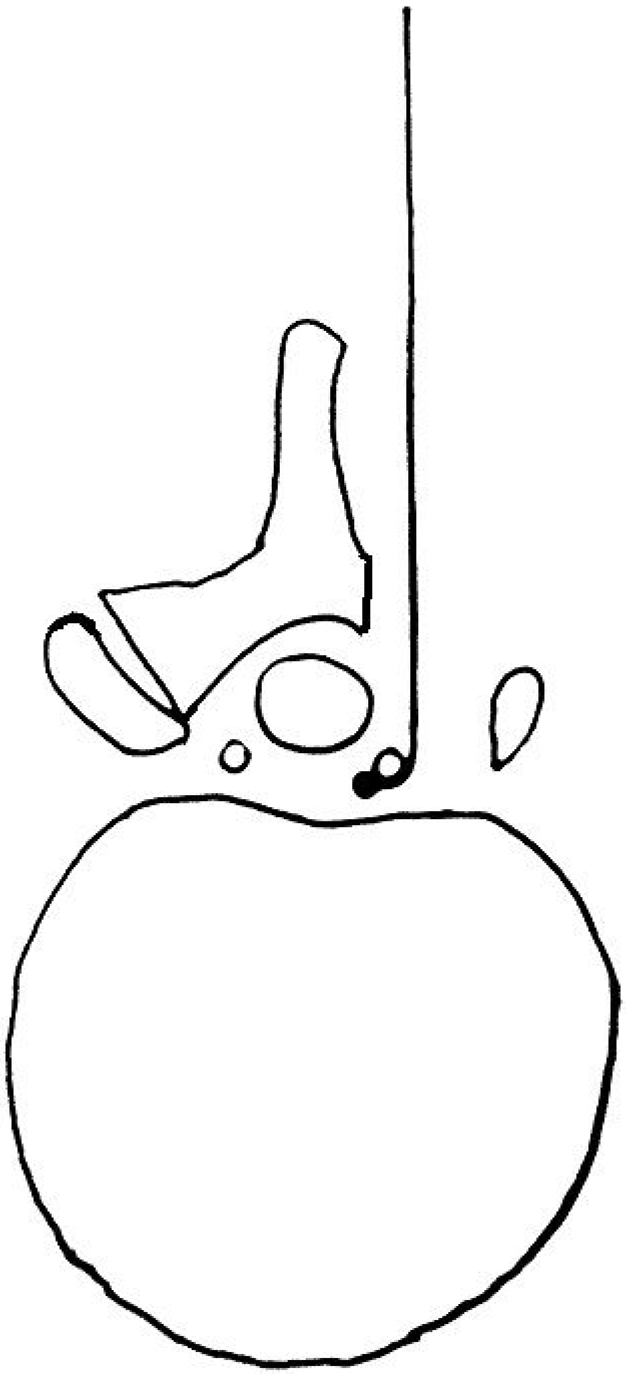

Figure 2

This figure shows how to use the the nerve root tension meter during surgery.