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ORIGINAL RESEARCH

Application of Neurophysiological Monitoring and Ultrasound Guidance in Intramedullary Decompression for Acute Spinal Cord Injury

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Objective: To explore the clinical application value of neurophysiological monitoring combined with ultrasound guidance in Acute spinal cord injury.

Methods: Ten patients with acute spinal cord injury underwent intramedullary decompression surgery under neurophysiological monitoring and intraoperative ultrasound guidance. ASIA (American Spinal Injury Association) classification and JOA (Japan Orthopaedic Association) scoring were performed preoperatively and postoperatively.

Results: The preoperative, 1-week postoperative, and 1-year postoperative JOA scores for the ten patients were (6.2 ± 1.55), (7 ± 1.58), and (11.8 ± 1.60), respectively. The JOA improvement rates at 1 week and 1 year postoperation were 7.4% and 51.9%, respectively. Among the patients, one patient had severe thoracic spinal cord injury upon admission, and their ASIA classification remained at Grade A after 1 year postoperation, while the remaining nine patients showed varying degrees of neurological function improvement.

Conclusion: Intraoperative neurophysiological monitoring combined with intraoperative ultrasound not only allows for timely monitoring of spinal cord function but also enables observation of whether decompression is adequate during surgery. It represents a very good surgical option for patients with spinal cord injuries.

Keywords: acute spinal cord injury, neurophysiological monitoring, intraoperative ultrasound, intramedullary decompression surgery

The global prevalence of acute spinal cord injury (ASCI) ranges from 236 to 1009 cases per million people, with a continuous upward trend in annual incidence.[1] In China alone, it is estimated that there are 759,302 ASCI patients, with 66,374 new cases occurring each year.[2] Most ASCI patients experience motor, sensory, and autonomic dysfunction following their injuries, and treatment outcomes are often suboptimal. Despite advancements in basic research and clinical surgical approaches for ASCI, effective treatment options remain limited.[3] Recent studies indicate that early intramedullary decompression can significantly enhance neurological recovery in ASCI patients.[4] The timing of surgical intervention is a critical factor influencing outcomes, with evidence suggesting that early decompression can lead to improved neurological results. For instance, a study highlighted that early decompression is preferred for both complete and incomplete injuries, with a notable consensus among neurosurgeons favoring this approach over that of orthopedic surgeons.[5] Neurophysiological monitoring and intraoperative ultrasound have proven to be valuable tools for real-time visualization of the spinal cord, facilitating precise decompression and reducing the risk of secondary injury. With advancements in technology, the integration of neurophysiological monitoring and intraoperative ultrasound holds great promise for enhancing the accuracy and safety of ASCI treatments, offering hope to the growing number of patients affected by this condition. Building on these findings, our department employed neurophysiological monitoring combined with intraoperative ultrasound guidance to perform intramedullary microdecompression on 10 ASCI patients, yielding favorable outcomes. The details are reported below.

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Subjects and Methods

Inclusion and Exclusion Criteria

For patients with spinal cord injuries admitted to our department, comprehensive routine examinations and preoperative assessments were conducted. Inclusion criteria for the application of this technique were as follows: (1) extensive edema resulting from spinal cord injury, with or without an accompanying intramedullary hematoma; (2) undergo surgery within 24 hours; (3) MRI sagittal T2-weighted imaging (T2WI) showing edema signals extending across more than two segments; (4) MRI sagittal T2WI revealing hematoma or softening necrosis signals near the dorsal aspect. Exclusion criteria included: (1) patients with penetrating spinal cord injuries; (2) complete spinal cord transection with clearly visible ventral dura mater and both ends of the spinal cord; (3) patients unable to tolerate anesthesia and surgery. After obtaining informed consent, intramedullary decompression surgery was performed under neurophysiological monitoring and ultrasound guidance, followed by postoperative neurological function assessment.

General Data

In this group of 10 patients, there were 7 males and 3 females, with ages ranging from 16 to 67 years, and an average age of 44.2 years. Preoperative X-ray, CT, and MRI examinations were conducted for all patients to determine the segment and severity of the spinal cord injury. The injuries included 7 cases of cervical segment injury, 2 cases of thoracic segment injury, and 1 case of thoracolumbar junction injury, all accompanied by varying degrees of vertebral injury (fracture or dislocation). Clinically, patients exhibited varying degrees of motor and sensory dysfunction in their limbs. The ASIA (American Spinal Injury Association) Impairment Scale and JOA (Japanese Orthopaedic Association) scores were utilized for grading and evaluation. All patients in this study obtained ethical approval from Anhui Medical University.

Intraoperative Electrophysiological Monitoring

Intraoperative electrophysiological monitoring was performed using a device to track somatosensory evoked potentials (SEP), motor evoked potentials (MEP), and electromyography (EMG), with electrodes placed according to the international 10/20 system.[6] SEP waves were utilized to assess the function of the dorsal and dorsolateral tracts of the spinal cord. During stimulation of the median or ulnar nerves in the upper limbs and the posterior tibial or common peroneal nerves in the lower limbs, a decrease in SEP wave amplitude of more than 50% and/or a latency increase of more than 10% indicated potential nerve injury. MEP waves were employed to evaluate the motor function of the anterior and lateral spinal cord tracts, monitoring the transmission of descending signals within the nervous system. Stimulation electrodes were positioned at C3 and C4, while recording electrodes were placed in the abductor pollicis brevis and abductor digiti minimi muscles of the upper limbs and in the tibialis anterior and extensor muscles of the lower limbs. A reduction in MEP wave amplitude of more than 80% suggested the presence of nerve injury. EMG was primarily used to monitor the patient's bowel and bladder function. A pair of needle electrodes were inserted into the bilateral anal sphincter muscles to continuously record resting potential activity, with an alarm triggered if high-frequency burst patterns were detected.

Intraoperative Ultrasound

The surgical field was filled with saline, and intraoperative ultrasound was employed to visualize the spinal cord and surrounding structures. In each case, the Aloka ARIETTA 60 ultrasound system (Hitachi Aloka Medical, Ltd.) was used. Real-time long-axis and short-axis images were captured along the entire length of the laminectomy. The scanning depth was adjusted as needed by the assistant. Decompression was considered sufficient if the subarachnoid space was visible both dorsally and ventrally around the spinal cord during the procedure. If decompression was deemed inadequate, further laminectomy was performed.

Surgical Procedure

After the patient was placed under general anesthesia and positioned prone, neurophysiological monitoring was initiated. C-arm fluoroscopy was employed to identify the spinal segment corresponding to the spinal cord injury. The surgery began with spinal stabilization using internal fixation to restore structural stability, followed by decompression of the spinal canal to relieve extradural pressure. The dura mater was then incised, and intramedullary decompression was performed under a microscope. At this stage, varying degrees of spinal cord swelling were observed. Intraoperative ultrasound was utilized to guide the localization of the contusion site within the spinal cord and to evaluate the adequacy of decompression. The spinal cord was incised along the posterior aspect of the lesion under the microscope, where contused tissue was observed extruding, significantly reducing spinal cord tension. If minor active bleeding occurred, it was controlled with gentle bipolar coagulation or compression with a gelatin sponge. The surgical area was irrigated with saline. Throughout the procedure, careful attention was given to any changes in motor and somatosensory evoked potentials as monitored by the neurophysiological equipment.

Observation Indicators

Neurological status was evaluated using the ASIA Spinal Injury Classification and the Japanese Orthopaedic Association (JOA) scoring system, following the International Standards for Neurological Classification of Spinal Cord Injury. Two physicians from the research team assessed and scored the patients preoperatively, one week postoperatively, and one year postoperatively.

ASIA Spinal Injury Classification: During follow-up, the ASIA classification was used to evaluate the spinal injury status of patients in both groups. Grade A: Complete loss of motor and sensory function below the injury level; Grade B: Sensory function is preserved below the injury level, but no motor function; Grade C: Motor and sensory function are preserved below the injury level, but more than 50% of key muscles have a muscle grade of less than 3;Grade D: Motor and sensory function are preserved below the injury level, and more than 50% of key muscles have a muscle grade of 3 or higher; Grade E: Complete recovery of motor and sensory function below the injury level.

Improvement Rate of JOA Score = (Postoperative JOA Score - Preoperative JOA Score) ÷ (17 - Preoperative JOA Score) × 100%

Results

1. The general condition and improvements in postoperative JOA scores and ASIA classifications for the 10 patients in this study are detailed in Table 1. There were no fatalities or serious complications, such as incision infections, among the 10 patients, and all were discharged in stable condition. Eight patients regained spinal cord function to a level that enabled normal daily activities (ASIA grades D and E).

2. Statistical analysis of the patients' ASIA spinal injury classifications before and after surgery revealed that 1 patient with a severe thoracic spinal cord injury remained at ASIA grade A one year postoperatively, while the remaining 9 patients exhibited varying degrees of neurological improvement (Table 1 and Table 2). For the 10 patients who

Table 1 Patient Demographics and Distribution of ASIA Impairment Scale and JOA Scores

Case	Gender	Age (years)	Injury Segment	Preoperative ASIA Grade	ASIA Grade 1Week Post-op	ASIA Grade 1 Year Post-op	Preoperative JOA Score	JOA Score 1Week Post-op	JOA Score 1Year Post-op
1	Male	67	Cervical	D	D	E	9	11	13
2	Male	44	Thoracic	A	A	A	7	7	8
3	Male	54	Cervical	C	C	D	8	10	13
4	Male	20	Cervical	B	C	E	3	5	17
5	Female	50	Cervical	C	C	D	6	8	13
6	Male	51	Cervical	C	C	D	1	3	6
7	Female	32	Cervical	C	C	D	5	6	12
8	Male	16	Thoracic	C	C	D	6	7	12
9	Female	48	Cervical	D	D	E	11	7	16
10	Male	41	Thoracic	C	C	C	6	6	8

Table 2 Distribution of ASIA Impairment Scales in Patients [n=10]

ASIA Impairment Scale	A	B	C	D	E
Preoperative	1	1	6	2	0
One Week Postoperative	1	0	7	2	0
One Year Postoperative	1	0	1	5	3

Table 3 Distribution of JOA Scores in 10 Patients [n=10, Scores]

	JOA Score	JOA Improvement Rate (%)
Preoperative	6.2 ± 1.55	
One Week Postoperative	7 ± 1.58	7.4
One Year Postoperative	11.8 ± 1.60	51.9

underwent intraoperative electrophysiological monitoring combined with ultrasound guidance, the JOA scores were (6.2 ± 1.55) preoperatively, (7 ± 1.58) one week postoperatively, and (11.8 ± 1.60) one year postoperatively. The JOA improvement rates at one week and one year postoperatively were 7.4% and 51.9%, respectively (Table 3).

3. Postoperative MRI follow-ups demonstrated adequate spinal cord decompression in all 10 patients. In 2 cases, intraoperative ultrasound monitoring detected inadequate decompression, which was corrected by extending the decompression further. This resulted in the appearance of the subarachnoid space around the spinal cord on ultrasound, indicating sufficient decompression (Figure 1A–D).

4. Intraoperative electrophysiological monitoring revealed no significant changes in MEP and SEP waves in 1 patient, while the remaining 9 patients showed an increase in MEP wave amplitude following decompression, with no significant changes in SEP waves (Figure 2A and B).

Discussion

The primary objectives of surgery for acute spinal cord injury (ASCI) are to achieve adequate decompression and restore spinal stability.[7] Studies have demonstrated that early decompression surgery can mitigate neural damage, improve prognosis, and reduce both ICU length of stay and post-injury complications.[8] A multicenter, non-randomized cohort study highlighted that early surgical intervention led to superior neurological outcomes at the 6-month follow-up, with improvements of more than 2 grades in the AISA assessment.[9] A recent study, utilizing data from four independent, prospective, multicenter sources, classified patients into early (<24 hours post-injury) and late (≥24 hours post-injury) decompression groups. Neurological outcomes were assessed using the ASIA or International Standards for Neurological Classification of Spinal Cord Injury (ISNCSCI) criteria. The findings indicated that surgical decompression within 24 hours of ASCI was correlated with enhanced sensory and motor recovery, identifying the first 24–36 hours post-injury as a critical window for achieving optimal neurological recovery through decompression surgery.[5,10–12] In ASCI cases, functional recovery is influenced not only by bony compression of the spinal cord but also by intramedullary edema and contusion lesions.[13,14] Following bony decompression, persistent tension in the dura mater and contusion lesions may continue to exert high pressure on the spinal cord, leading to inadequate blood flow improvement and ongoing cytotoxic and vasogenic edema.[15] Consequently, intramedullary decompression can more effectively relieve pressure and improve outcomes, as supported by numerous clinical trials and animal studies.[16,17]

In spinal cord injury surgery, there is a risk of inducing mechanical or ischemic damage to the spinal cord. To mitigate this risk, intraoperative monitoring of spinal cord function is crucial. From the 1970s to the 1990s, somatosensory evoked potentials (SEP) and motor evoked potentials (MEP) were gradually introduced for this purpose. Neurophysiological monitoring, which includes SEP, MEP, and electromyography (EMG), provides real-time feedback on the integrity of sensory and motor conduction pathways within the nervous system. These techniques are now widely adopted in spinal cord surgeries, and in 2022, an expert consensus was established to further promote

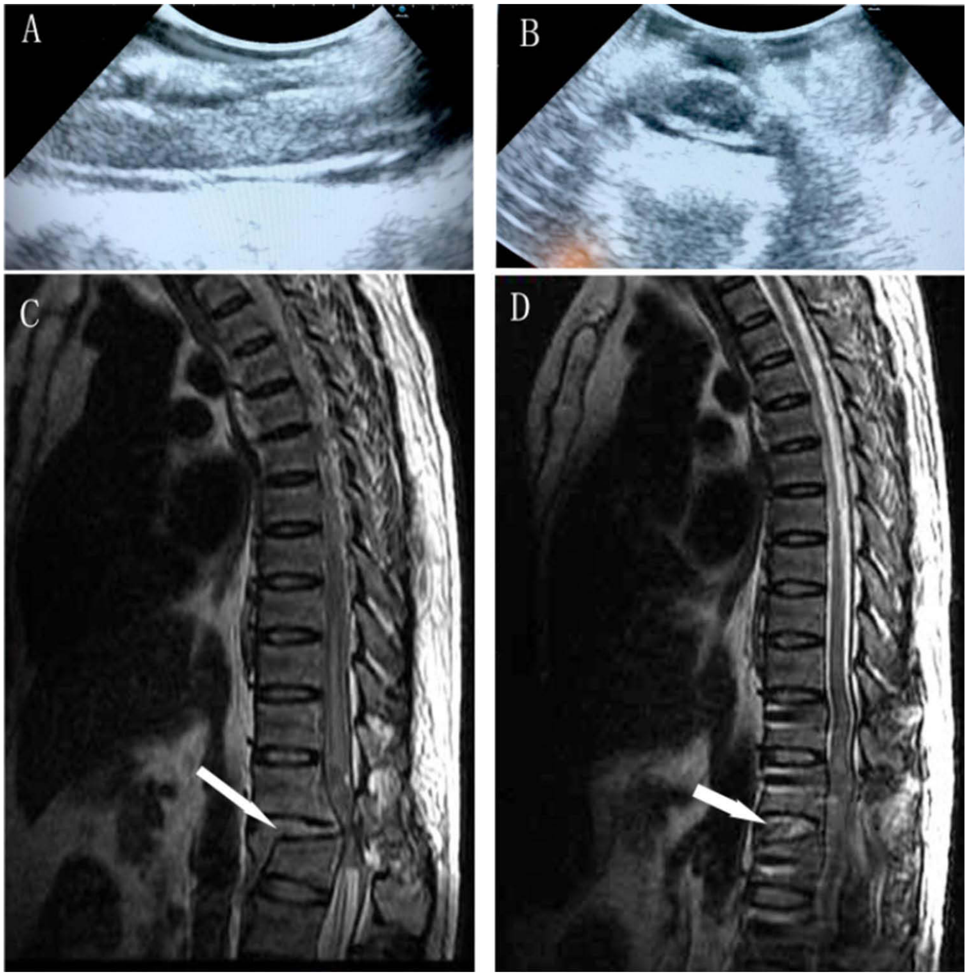

Figure 1 Intraoperative ultrasound imaging and comparison of preoperative and postoperative MRI examinations. The intraoperative ultrasound image shows the restoration of spinal cord morphology to normal in the sagittal plane (**A**) and axial plane (**B**) after decompression surgery. (**C**-**D**) displays a comparison of preoperative and postoperative magnetic resonance images (Arrows indicate the injured site).

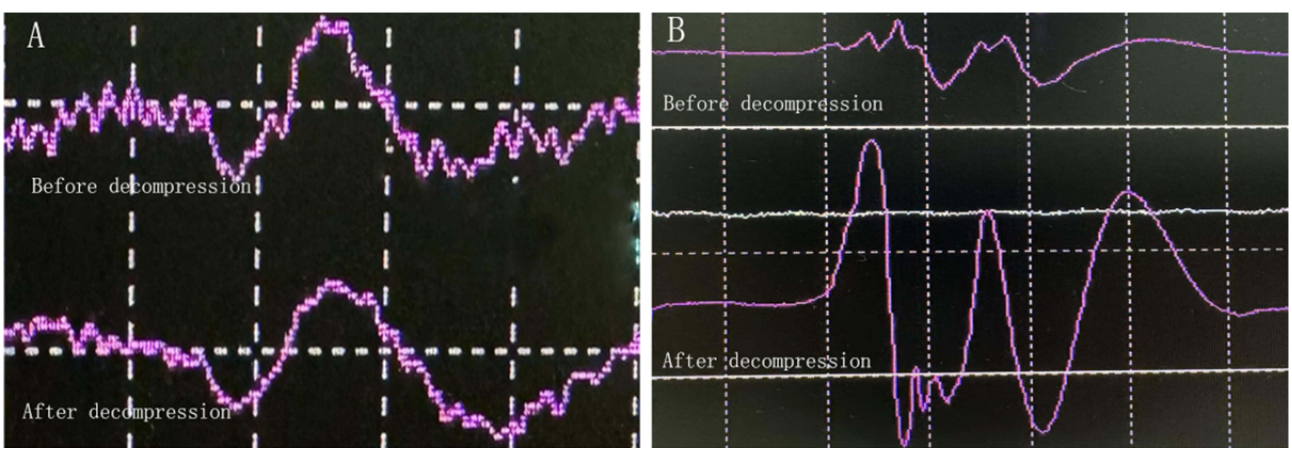

Figure 2 Intraoperative electrophysiological changes before and after decompression: (**A**) shows the change in somatosensory evoked potentials before and after decompression, with no significant waveform changes observed; (**B**) shows the change in motor evoked potentials before and after decompression, with a significant increase in amplitude.

the use of electrophysiological monitoring in spinal and spinal cord surgeries.[18] In this study, 9 patients demonstrated significant recovery of spinal cord function, while 1 patient showed only mild improvement. Among those with significant recovery, there was a notable change in MEP amplitude before and after decompression. In contrast, the patient with mild improvement exhibited no significant change in MEP amplitude. These findings suggest that neurophysiological monitoring during decompression surgery for acute spinal cord injury has predictive value for the postoperative recovery of spinal cord function.

In recent years, ultrasound monitoring of spinal cord morphology has been increasingly utilized during surgeries, enabling dynamic observation and real-time assessment of spinal cord shape. After laminectomy in patients with spinal cord injury, intraoperative ultrasound provides crucial imaging of the spinal cord and subarachnoid space, accurately identifying contusion areas and minimizing the risk of additional spinal cord injury during surgical exploration. For patients with severe spinal cord injuries, characterized by significant contusion and edema, postoperative MRI often reveals inadequate decompression. However, real-time intraoperative ultrasound can assess the adequacy of decompression by monitoring the spinal cord and subarachnoid space. In this study, two patients were identified via intraoperative ultrasound as having insufficient decompression after laminectomy. After timely surgical expansion, postoperative MRI confirmed that spinal cord morphology had been restored, achieving complete decompression. Continuous dynamic ultrasound monitoring during surgery ensured that no spinal cord injuries or other complications occurred, with the spinal cord morphology returning to normal. This was evidenced by a clear subarachnoid space, a straight anterior dural sac echo line, and significant improvements in JOA scores during postoperative follow-up.

In this study, we built upon the traditional approach of internal fixation and bony decompression by using microsurgical techniques for further decompression of the injured spinal cord. This approach aimed to, on one hand, relieve the restrictions imposed on the spinal cord by the dura mater and pia mater, achieving complete decompression both inside and outside the spinal cord; on the other hand, to remove intramedullary hematomas, necrotic tissue, and local inflammatory factors, thereby mitigating secondary pathophysiological responses. Intraoperative real-time ultrasound guidance combined with neurophysiological monitoring provided a high level of safety during the surgery. All 10 spinal cord injury patients who underwent this procedure experienced varying degrees of neurological recovery.

Limitations of This Study

This study is a retrospective single-center analysis that lacks randomized control trials. The statistical analysis is conducted on a relatively small sample size, which may introduce bias and limit the generalizability of our findings. The assessment of the degree of decompression during the procedure relies on a single surgical team, potentially leading to variability in evaluations. Furthermore, the timing of postoperative MRI reviews was not standardized, resulting in inconsistent evaluation metrics.

Conclusion

Neurophysiological monitoring combined with ultrasound in intramedullary decompression surgery is a safe and effective treatment method. This method can monitor the spinal cord function in real time during surgery and ensure full decompression, thereby supporting the recovery of neurological function of patients with spinal cord injury. It is necessary to further analyze to verify these discoveries, especially using a larger sample amount to enhance statistically significance. The integration of advanced imaging technology and comprehensive follow-up evaluation may provide more insights on the long -term impact of this surgical method on the prognosis of patients.

Ethics

We confirm that the present study complies with the principles of the Declaration of Helsinki.

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Disclosure

The authors report no conflicts of interest in this work.

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