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Research Article

Early Detection of Brachial Plexus Injury in Prone Position Surgery Using Multimodal Intraoperative Monitoring: A Cross-sectional Study

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Abstract

Background: Individuals undergoing spinal surgery are susceptible to position-related nerve injuries, a significant issue that warrants attention.

Objectives: To enhance patient safety in spinal surgery by optimizing positioning and preventing position-related nerve injuries during prone surgical procedures.

Methods: This study employed a cross-sectional design.

Data were collected from a survey conducted at the First Affiliated Hospital of Sun Yat-sen University, encompassing 93 patients who underwent spinal surgery in the prone position. After general anesthesia, bilateral upper limb brachial plexus nerve function was monitored using Multimodal Intraoperative Monitoring (MIOM) for timely diagnosis and postural adjustment according to abnormal MIOM signals.

Results: A total of 10 cases (10.75%) exhibited position-related waveform abnormalities, including 5 instances of SSEP/MEP waveform disruptions, a single case of MEP waveform abnormality, and 4 instances of EMG waveform irregularities. After screening and adjustment of the affected limbs, the MIOM signals all returned to baseline levels, and none showed clinical manifestations of neurological dysfunction postoperatively.

Conclusion: In the context of posterior spine surgery performed with patients in the prone position, MIOM serves as a vital tool for alerting to potential neurological injuries associated with positioning, facilitating prompt and efficacious intervention to mitigate the risk of position-related neurological harm.

Keywords: Brachial plexus injury; Neuromonitoring; Prone position; Spinal surgery; Surgical safety

Introduction

The Prone Position in Posterior Spinal Surgery The prone position is frequently utilized for posterior spinal surgeries due to its benefits in enhancing surgical access and facilitating operative maneuvers [1]. However, patients under general anesthesia are incapable of independently adjusting their position, which can precipitate severe complications, including vision loss, peripheral nerve damage, and even permanent disability, if positioning is not executed correctly [2]. Furthermore, the necessity for intraoperative decompression, implantation, and adjunctive orthopedic and radiographic assessments often necessitates position adjustments, thereby heightening the risk of nerve injury. Despite efforts to prevent compression injuries from positioning and protecting the peripheral nerves during surgery, 0.14% of peripheral nerve injuries result from improper operative placements, and brachial plexus nerve injury accounts for 36% [3,4].

The Utility of Multimodal Intraoperative Monitoring (MIOM) provides a real-time assessment of spinal cord and nerve functionality, enabling the detection of nerve damage associated with positional neglect of the upper extremities. This modality not only mitigates the risk of spinal and nerve injuries but has also become an integral component of spinal surgical procedures. Studies have shown that the MIOM technique prevents spinal cord and nerve root injuries during body position placement and cervical spine surgery [5]. However, there needs to be more literature on how nursing staff can manage the risk of position-related nerve injury with the help of MIOM. Given this, this study examines the role of MIOM in early warning of position-related nerve injury and develops nursing countermeasures to provide a reference for operating room care.

Rationale

To improve postural safety and avoid postural-related nerve injury in patients undergoing surrendering prone position surgery of the spine.

Methods

Study Design and Setting

This investigation adopted a cross-sectional and quantitative approach, aimed at enhancing postural safety and circumventing nerve injuries related to positioning in patients undergoing spinal surgery in the prone position.

Participants

Ethical Approval and Recruitment The study received approval from the Institutional Review Board. Eligible participants consisted of patients who underwent posterior spinal surgery with MIOM at the First Affiliated Hospital of Sun Yat-sen University between July 2021 and June 2022. All participants provided informed consent prior to their inclusion in the study.

Inclusion Criteria

Participants were selected based on a preoperative diagnosis encompassing spinal degenerative conditions, trauma, deformities, infections, or tumors. They were classified according to the American Society of Anesthesiologists (ASA) criteria levels I to III. Inclusion also required an intraoperative assessment of spinal cord and nerve root function through a combination of Somatosensory Evoked Potential (SSEP), Motor Evoked Potential (MEP), triggered electromyography, and free electromyography, by the established surgical protocol. Participants were required to provide voluntary consent and sign an informed consent form.

Exclusion Criteria

Patients were excluded if they required frequent intraoperative adjustments in surgical positioning. Additionally, individuals with preoperative neurological dysfunction affecting the upper extremities were not eligible. The use of inotropes and inhalation anesthetics during the monitoring period also warranted exclusion. Other contraindications to MIOM included a history of epilepsy, cranial defects or implanted metal devices, and the presence of a pacemaker [6]. Study Population The study comprised 93 patients, with 54 females and 39 males. The underlying causes for surgery were idiopathic in 46 cases, congenital in 23, tuberculosis in 5, neurofibromatosis in 10, and neuromuscular in 9. The spinal deformities included 8 cases of scoliosis, 14 of kyphosis, and 71 of kyphoscoliosis. Surgical interventions spanned from the T3 to L5 spinal segments and were conducted by a surgical team headed by the principal investigator. Detailed information is listed in Table 1.

Variables	Detail	N (%)
Number of Patients		93
Mean age (years)	32.33±17.40	
sex ratio	Male	39 (41.94%)
	Female	54 (58.06%)
Mean BMI (kg/m^2)	20.68 ±3.89	
Diagnosis	Kyphoscoliosis	71 (76.30%)
	Kyphosis	14 (15.10%)
	Scoliosis	8 (8.60%)
Etiologies	congenital	23 (24.70%)
	idiopathic	46 (49.50%)
	neurofibromatosis	10 (10.80%)
	neuromuscular	9 (9.70%)
	tuberculosis	5 (5.40%)
Instrumentation	All pedicle screw system	93 (100%)

Abbreviations: BMI: Body Mass Index; IS: Idiopathic Scoliosis; CS: Congenital Scoliosis; CSR: Congenital Scoliosis Revision; TB: Tuberculosis; NF: Neurofibromatosis; NM: Neuromuscular; NMR: Neuromuscular Revision; SSEP: Spinal Somatosensory Evoked Potential; MEP: Motor Evoked Potential; EMG: Electromyogram

Table 1: Patients' Preoperative Demographical characteristics and clinical data.

Patient or Public Contribution

This observational study utilized data collected from patients during routine clinical care without the need for additional interventions. The study protocol was approved by the Ethics Committee, and all participants were thoroughly informed and provided consent before the collection of any data.

Description of Experiment, Treatment, or Surgery

Description of Anesthesia Protocol

Endotracheal Intubation was performed for airway management. Notably, no volatile anesthetics were administered during the induction or maintenance of anesthesia, and neuromuscular blocking agents were also excluded from the surgical procedure.

Surgical Positioning

Tailoring to the specific surgical requirements and individual patient morphology, suitable positioning aids were chosen and affixed to the transfer bed. Upon achieving effective anesthesia, the patient was meticulously transferred to the operating bed by a team of four healthcare professionals. Utilizing the axial turning technique, the patient was repositioned into the prone posture with precision and secured to preclude the risk of falls. The patient's eyes, cheekbones, mouth, and nose were checked and confirmed to be suspended; the head was placed on a headrest, and the cervical spine was kept in a neutral position; the thorax and abdomen were kept suspended to avoid pressure on the perineum and breast; the upper limbs were placed on the front and outside of the head with 90° of shoulder and elbow flexion, the legs were naturally bent and kept in a functional position to avoid pressure on both knees, and the toes were naturally lowered and suspended [7]. Intraoperatively, the patient's position was closely observed, and the patient's head and limbs were elevated every 1 to 2 hours to temporarily relieve the local pressure under the conditions permitted by surgery.

Electrophysiological Signal Monitoring Equipment and Methods

Electrophysiological Signal Monitoring Equipment

All participants were monitored using neurophysiological devices manufactured by Natus, which included the application of single-use subcutaneous needle electrodes and disc electrodes of the paste variety. Further details regarding the specific models utilized are delineated in Table 2. Operated by the same neurophysiological professional, the whole process of real-time continuous monitoring and collection of corresponding data.

Equipment	Manufacturers	Model/version
Intraoperative electrophysiological monitor	Natus (USA)	Nicolet Endeavor CR
Monitoring software(self-contained)	Natus (USA)	Endeavor
Disposable hypodermic needle electrodes	Natus (USA)	019-476800 019-475700
Disc electrode (paste type)	Natus (USA)	019-401400

Table 2: Neurophysiological monitoring equipment and software models.

Electrophysiological Monitoring Method

A 16-channel neurophysiological monitoring system was engaged to concurrently track SSEP, MEP, and EMG, thereby assessing neurophysiological alterations [8]. Post-anesthesia, baseline data were established prior to surgical positioning. Throughout the surgical procedure, real-time monitoring of SSEP, MEP, and EMG waveforms was conducted, with any anomalies meticulously documented. Intraoperative SSEP monitoring is 10 minutes/time, MEP monitoring frequency is 30 minutes/time, and the frequency of monitoring is increased when the surgery is needed or when the key steps are taken, and EMG is monitored in real-time.

MIOM Monitoring Sites

SSEP assessments focused on the functional integrity of the neural pathway extending from peripheral nerves to the cerebral cortex, with stimulation points identified at the median nerve of the upper extremity and the posterior tibial nerve of the lower extremity. MEP evaluations spanned the entire motor conduction pathway, from the motor cortex to the target muscles, encompassing a range of muscles such as the biceps, triceps, brachioradialis, deltoid, thumb adductor, piriformis, lateral femoral, anterior tibial, and muscles responsible for thumb extension and retraction. EMG served to document the electrical activity of muscles, capturing resting potentials under normal conditions.

Assessment of Abnormal Electrophysiological Signals and Nursing Interventions

Criteria for Identifying Intraoperative Neurophysiological Abnormalities: Utilizing the established 50/10 rule as a benchmark against baseline readings, three real-time monitored waveforms were evaluated: SSEP amplitudes that diminished by more than 50% or latencies that extended by more than 10% from baseline were deemed abnormal; similarly, an abrupt 80% reduction or complete loss of MEP amplitude was classified as abnormal [9]. The continuous presence of action potentials in EMG recordings was also indicative of an abnormality.

Intraoperative Care Measures Post-Detection of Abnormalities: In response to abnormal MIOM findings, nursing staff immediately liaised with the surgical team to facilitate patient repositioning and alleviate any undue tension or compression. Effectiveness in position adjustment was gauged by the restoration of SSEP and MEP waveforms to baseline levels or within the normal amplitude range, as well as the normalization of EMG readings. The disposition process for identifying abnormal neurophysiological signals is shown in Figure 1.

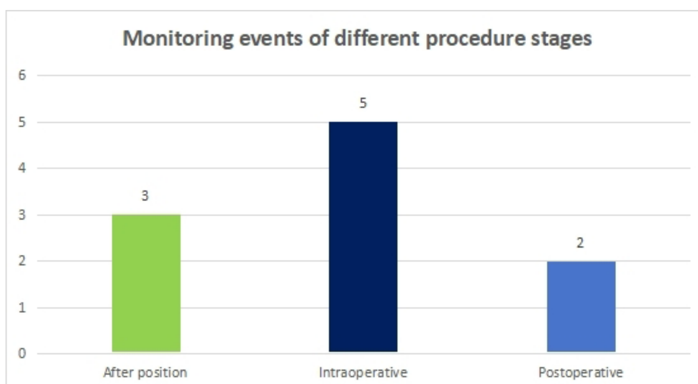


Figure 1: The disposition process for identifying abnormal neurophysiological signals.

Data Sources

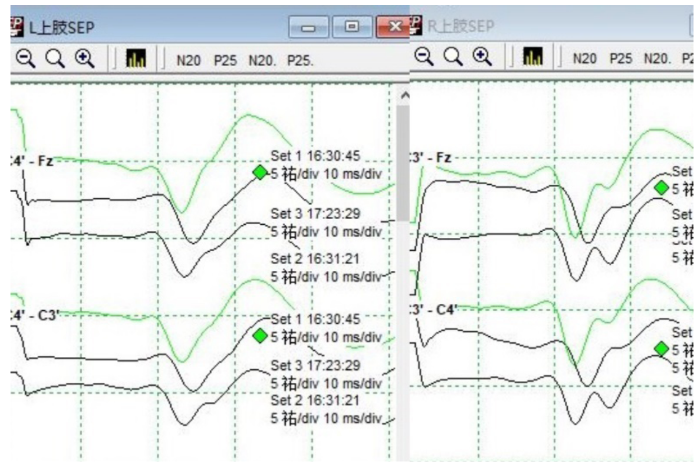
Ethical approval for this study was granted by the Biomedical Ethics Review Committee of the First Affiliated Hospital of Sun Yat-sen University, enabling the interview of participants and the collection of relevant data.

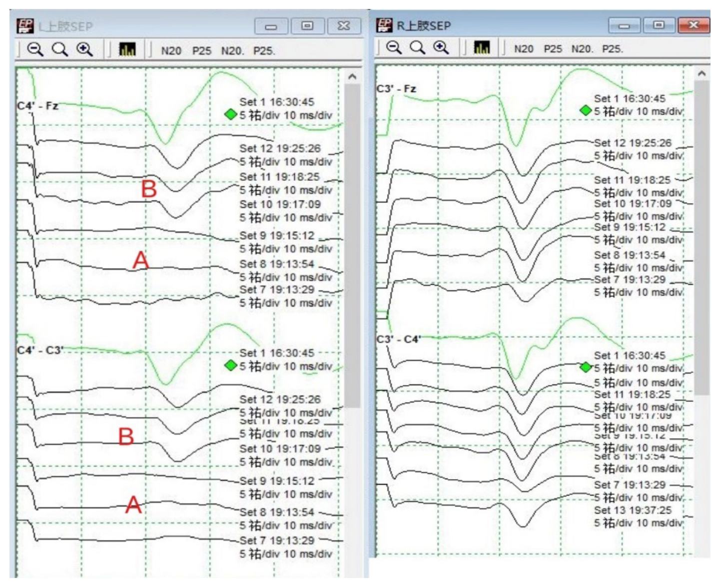
Statistical Analysis

Data were organized in Excel, with mean and standard deviation utilized to delineate variable distributions, and percentages used to represent categorical and ranked variables. All statistical analyses were conducted using SPSS software (version 26, Chicago, Illinois, USA).

Results

Table 3 illustrates that 10 cases (10.75%) exhibited position-related waveform anomalies, comprising 5 instances of combined SSEP/MEP waveform irregularities, a solitary case of MEP waveform abnormality, and 4 EMG waveform anomalies. Upon identification of these anomalies, the operating room nurses swiftly addressed postural discrepancies, and subsequent fine-tuning of patient positioning returned all waveforms to baseline levels. Post-surgical assessments revealed no incidence of new neurological deficits or exacerbation of pre-existing neurological conditions. Figures 2-3 depict the SSEP monitoring variations in the bilateral upper limbs for case 6. Upon application of traction to the left upper extremity, an immediate positive SSEP response was observed, which returned to normal levels within 3 minutes following the prompt cessation of traction by the nursing staff.





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Number	DX	Sex	Age	BMI	Blood	BP	Type of EP(+)	Procedure stages	Reason	Intervention	Outcome	Last follow-up
1	EP	F	16	16.65	300	96/63	SSEP/MEP	After position	Loss of limb support	Reposition the brace and upper limbs	N (-)	N (-)
2	EP	F	26	21.67	300	117/62	SSEP/MEP	Intraoperative	Limb compression	Relieve compression and adjust the position of the upper limb	N (-)	N (-)
3	EP	M	24	19.49	500	132/77	SSEP/MEP	Intraoperative	Loss of limb support	Reposition the brace and upper limbs	N (-)	N (-)
4	EP	F	64	20.28	500	141/78	MEP	Postoperative	Limb compression	Relieve compression and adjust the position of the upper limb	N (-)	N (-)
5	EP	M	45	24.01	200	138/75	EMG	After position	Limb compression	Relieve compression and adjust the position of the upper limb	N (-)	N (-)
6	IS	M	47	21.45	100	113/73	SSEP/MEP	Intraoperative	Limb pulling	Restore functional positions and properly immobilize upper limbs	N (-)	N (-)
7	EP	M	18	20.20	1000	127/77	EMG	Postoperative	Limb compression	Relieve compression and adjust the position of the upper limb	N (-)	N (-)
8	EP	M	36	26.75	1400	118/81	SSEP/MEP	After position	Limb compression	Relieve compression and adjust the position of the upper limb	N (-)	N (-)
9	IS	M	25	15.78	1000	116/61	EMG	Intraoperative	Limb compression	Relieve compression and adjust the position of the upper limb	N (-)	N (-)
10	NF	M	38	21.87	200	123/82	EMG	Intraoperative	Limb pulling	Rotate both shoulder joints and forearms inward to palms facing inward	N (-)	N (-)

DX: Diagnosis; EP: Evoked Potential; IS: Idiopathic Scoliosis; NF: Neurofibromatosis; F: Female; M: Male; BP: Blood Pressure; SSEP: Somatosensory Evoked Potential; MEP: Motor Evoked Potential; EMG: Electromyogram

Table 3: Clinical Outcomes of Positive Monitoring Patients

Discussions

Background: The Utility of MIOM in Early Detection of Brachial Plexus Injury During Prone Positioning

Positional adjustments or fixation under anesthesia may result in peripheral nerve injury when pressures and tensions exerted on soft tissues, nerves, or blood vessels surpass the body's physiological tolerance thresholds [10]. It is incumbent upon circulating nurses to adhere to the principles of proper surgical positioning, maintain vigilant intraoperative observation, and enforce protective measures to mitigate nerve injuries stemming from pressure and traction. Notably, the prompt identification and rectification of positional anomalies that heighten the risk of nerve injury are pivotal to ensuring surgical safety [11]. The detection of abnormal electrophysiological signals through MIOM monitoring is indicative of neurological compromise and warrants immediate and serious attention. In all patients in this study with abnormal MIOM signals, the electrophysiological signals could be restored to baseline levels after timely adjustment of the abnormal body position associated with neurological impairment, i.e, neurological impairment could be restored after timely intervention. Postoperative ward follow-up revealed that none of the ten patients exhibiting abnormal neurophysiological monitoring readings developed any new neurological deficits post-surgery.

This underscores that timely and appropriate intervention upon detection of abnormal MIOM signals can prevent position-related neurological damage, thereby highlighting the critical role of MIOM in mitigating such injuries.

Prior research has documented a range of nerve injuries attributable to improper positioning, encompassing the radial, ulnar, brachial plexus, and anterolateral femoral cutaneous nerves, among others.

The predominant symptoms include numbness, sensory deprivation, and impaired limb function within the affected regions. Recovery from nerve injuries can span from several days to several months. Certain injuries are irreversible, potentially resulting in permanent disability and profoundly impacting the patients' physical and psychological well-being [3,12]. The absence of such cases in this study indicates that prompt detection and removal of causative factors can accelerate recovery from minor nerve injuries. Upon identification of abnormal MIOM signals, the monitoring team promptly alerted the circulating nurses to conduct an immediate postural abnormality assessment, thereby reducing the duration of exposure to factors that could impair neurological function. This also substantiated that the intervention protocol employed in this study was both feasible and practical.

Rationale: Cause Analysis and Nursing Interventions

Loss of Limb Support: From this study, Loss of limb support is a phenomenon that can transpire during surgery, often linked to alterations in the support platform or positional adjustments of the limbs. In one of our patients, the proper upper limb position was changed to cause elbow suspension due to the adjustment of the brace by the radiology technician during the intraoperative O-arm X-ray examination, which resulted in the loosening of the brace. Independent of MIOM, nursing personnel must remain vigilant to any factors that could compromise the patient's postural support infrastructure following the utilization of surgical equipment, especially intraoperative X-ray examination equipment to enter and exit the operative field (which may be accompanied by postural adjustments such as surgical bed lift, lateral tilt, head and tail tilt, and translation). Within this cohort, one patient experienced an intraoperative disruption in the evoked action potential sequence, leading to the left lower extremity becoming suspended off the bed. It is recommended that nursing staff vigilantly ensure the secure restraint or fixation of all patient limbs to prevent the loss of support and potential injury.

Limb Compression: The study revealed that limb compression is a risk throughout all phases of surgery, often correlated with the excessive tightness of restraint belts during the preoperative positioning process. Nursing staff must routinely assess the tightness of restraints post-implementation to mitigate the risk of injury from overly constrictive limb bindings. Compression of the patient's limb by the surgeon during surgery is identified as a potential cause of abnormal MIOM signals. This underscores the importance for nursing staff to ensure ample and comfortable space for the surgeon during patient positioning. And regularly check whether the surgeon is compressing the patient's nerve-vulnerable parts. In the case of obese patients, particular care must be taken during postoperative transfer using a transfer bed to prevent nerve injury due to compression of the upper limbs against the bed's lateral barriers.

Limb Pulling: Findings from this study indicate that limb strain predominantly occurs during the preoperative phase, with instances also noted during the intraoperative period. Specifically, during preoperative positioning for posterior cervical spine procedures, excessive external rotation of the shoulder joints and forearms could trigger abnormal MIOM signals within the upper extremities. This suggests that nursing staff should pay attention to fixing the patient's upper extremities in a position with both shoulder joints and forearms internally rotated, with the palms facing inward when performing such position placement. In addition, intraoperative arousal and pain stimulation may also cause hyperextension of the patient's limbs, which may also lead to abnormal MIOM signals under certain conditions. Nursing staff must conduct routine post-arousal position checks on patients, a practice that is particularly critical for those undergoing surgery without the benefit of MIOM monitoring [13].

Limitations

The study acknowledges several intrinsic limitations. As a single-center cross-sectional survey, it provides limited evidence to establish a robust causal link between brachial plexus injuries and specific surgical positions. Future research should involve a multicenter, randomized controlled trial designed to ascertain the relationship between the angular positioning of the upper limbs, applied traction forces, and the incidence of brachial plexus injuries. Additionally, longitudinal studies are warranted to delve deeper into causality and to formulate more efficacious intervention strategies. Nonetheless, this study represents a crucial exploration, laying foundational insights for the safety considerations of MIOM during the prone positioning of the upper extremities.

Generalizability: Implication for Operating Room Nursing

This study corroborates the heightened risk of brachial plexus nerve injuries associated with the descending prone positioning of the upper extremities. MIOM is capable of furnishing early warnings of postural nerve injuries occurring in the prone position. Moreover, the circulating nurse can mitigate the risk of postural nerve injuries through the provision of tailored care to the upper extremities during the prone positioning process. Initially, active engagement in preoperative discussions is essential to comprehend the surgical approach and specific positioning demands. Secondly, to preclude nerve strain or compression in the upper extremities, the positioning of posture pads and the extremities should be meticulously adjusted in accordance with the patient's upper extremity condition before final positioning. Lastly, ensuring adequate support for the upper limbs is crucial to prevent complete suspension and potential nerve compromise.

Conclusion

The findings of this study underscore that during spinal surgeries performed in the prone position, improper placement of the upper limbs, be it compression or tension on the brachial plexus, poses a risk of damage to the nerves of the upper limbs. It is imperative for surgical personnel, particularly circulating nurses, to vigilantly monitor changes in the patient's surgical positioning throughout the perioperative period, with particular attention required following intraoperative X-ray imaging. Position-related nerve injuries are predominantly attributed to limb compression, strain, and the collapse of postural support, which are the pivotal postural deviations that must be addressed. Concurrently, MIOM offers a real-time alert system for peripheral nerve function, enabling the early detection of nerve injuries and the identification of affected limbs. Medical staff can leverage MIOM monitoring outcomes to identify postural irregularities, thereby effectively circumventing position-related nerve injuries. Should MIOM monitoring not be accessible, nursing staff and positioning technicians can still minimize the risk of position-related nerve injuries by employing dependable and functional limb supports, correctly securing the patient's position, and conducting routine checks for postural deviations following any surgical or procedural steps that could induce positional shifts.

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