Orthopaedic Surgery

CLINICAL ARTICLE

Multi-modal Neuroelectrophysiological Monitoring in the Treatment of Thoracic Tuberculosis with Debridement and Bone Grafting and Posterior Pedicle Screw Fixation *via* Costal Transverse Process Approach

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Objective: To explore the value of multi-mode neuroelectrophysiological monitoring (MIOM) in evaluating spinal cord and nerve root function in the treatment of thoracic tuberculosis *via* costal transverse process approach.

Methods: From December 2017 to September 2019, a retrospective study of thoracic tuberculosis patients in our hospital was conducted. This study included 25 patients (14 men and 11 women). The average age of patients at the time of surgery was 63.3 years (range, 20–83 years). All patients (three cases with the destruction of a single vertebral body, 13 cases with the destruction of two vertebral bodies, and nine cases with the destruction of three or more vertebral bodies) underwent costal transverse process approach with debridement and bone grafting and internal fixation combined with intraoperative multimodal neuroelectrophysiological monitoring. During the operation, somatosensory evoked potential (SEP), transcranial electrical stimulation motor evoked potential (TES-MEP), and spontaneous electromyography (EMG) were used to monitor progress. ESR, visual analogue scale (VAS), Cobb angle, and Oswestry disability index (ODI) were statistically analyzed to evaluate the treatment effects and patient satisfaction.

Results: All 25 patients were successfully monitored. The follow-up time ranged from 12 to 21 months, with an average of 15.3 months. SEP waveform abnormalities occurred in five patients during the operation, the incidence rate was 28%. Of these five patients, three patients changed their instruments and postures, and adjusted the flushing water flow in time; one patient received pressure therapy in time; the operation was suspended for 10 min for one patient. There were seven cases with abnormal TES-MEP waveform, the incidence rate was 28%. Among these seven cases, five cases adjusted the nail path during the operation and adjusted the nail position in time. One case adjusted the inclination angle of the operating table in time; one case completed the contralateral nail stick correction in time; five of them had abnormal TES-MEP waveforms, and EMG burst potential was also detected, the incidence rate was 20%. After prompt treatment, the abnormal waveforms of all patients returned to normal; no abnormal waveforms, recurrence of tuberculosis, loosening of internal fixation, nerve and spinal cord dysfunction, etc. The VAS score, erythrocyte sedimentation rate (ESR), Cobb angle, and ODI scores of the patients 1 year after operation were significantly improved compared with 1 week after operation ($P < 0.05$).

Conclusion: Multi-mode intraoperative electrophysiological detection combined with costal transverse process approach for the treatment of thoracic tuberculosis could avoid intraoperative nerve and blood vessel damage, reduce surgical risk, improve surgical efficiency, and ensure curative effect.

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Key words: Costal transverse process approach; Multi-modal electrophysiological monitoring; Posterior pedicle internal fixation; Thoracic tuberculosis

Introduction

Tuberculosis (TB) is still one of the most common infectious diseases in the world[1]. Bone and joints infected with tuberculosis account for about 10%–15% of cases of extrapulmonary tuberculosis. Spinal tuberculosis occupies the first place in bone and joint tuberculosis with an incidence rate of 40%–50%. With the increase of human immunodeficiency virus (HIV) infection rate and drug-resistant strains, the incidence of spinal tuberculosis is increasing year by year[2,3]. Because the pathological process is serious for providing 70%–90% of the anterior middle column injury, the biomechanical stability of the spine is seriously affected during the course of the disease, resulting in spinal instability and neurovascular damage, and serious complications such as kyphosis and paraplegia. Thoracic tuberculosis accounts for about 39.8% of spinal tuberculosis. In recent years, the number of patients with spinal tuberculosis in China has shown an increasing trend. It is difficult for anti-tuberculosis drug treatment to penetrate the sclerotic bone formed by tuberculosis lesions and it cannot directly achieve effective antibacterial or bactericidal blood concentrations around the lesions. Therefore, the use of drugs only is not effective enough to treat spinal tuberculosis. Current studies have shown that surgical treatment of spinal tuberculosis has achieved a certain effect. For example, high spinal tuberculosis such as single-segment or multi-segment tuberculosis of the thoracic spine can be operated on to remove the lesion, decompress the spinal nerve, correct kyphotic deformity, and reconstruct spinal stability. There are a large number of reports that first- or second-stage anterior lesion removal and posterior internal fixation have achieved good results in the treatment of spinal tuberculosis. The main advantages of posterior fixation: (i) tuberculosis lesions mostly invade the spine vertebral body and intervertebral space, while the pedicle and appendages are mostly normal. Therefore, the pedicle screw is placed in the adjacent normal segment posteriorly, and the lesion and the internal fixation are isolated from each other, which avoids the risk of prolongation of the lesion due to direct contact between the internal fixation and the tuberculosis lesion; (ii) posterior pedicle screw internal fixation and correction can restore and reconstruct the spine series. The spinal cord can move back to a certain extent, increasing the buffer gap between the lesion and the spinal cord, and improving the safety of lesion removal; and (iii) the posterior pedicle screw fixation is a three-column fixation, and the fixation is firm. The correction of severe kyphosis is better than the anterior fixation alone, which can better reconstruct the stability of the spine and the sagittal plane sequence[4,5]. For the treatment of thoracic spine tuberculosis with surgical indications, studies have shown that debridement combined with strong posterior internal fixation has a definite effect on tuberculosis infection symptoms and thoracic spine function. Among them, the costal transverse process approach combined with bone grafting and posterior pedicle screw internal fixation is widely used, because it has the advantage of one position and one incision without entering the chest cavity. There are many important blood vessels on the anterior side of the thoracic spine, which greatly increases the difficulty of pedicle screw implantation and lesion removal[6]. In addition, the diameter of the cylindrical spinal canal of the thoracic pedicle and spinal cord is small, which means that the implantation of the pedicle screws can easily cause serious neurological complications[7]. Therefore, it is extremely important and challenging to detect and prevent intraoperative damage in time during thoracic tuberculosis surgery. Recently, the multi-mode neuroelectrophysiological detection (MIOM) technology has been widely recognized and applied in the monitoring of spinal surgery, because of its definite effect. During the operation, MIOM can promptly warn of new spinal cord and nerve root damage, and remind the surgeon to stop or improve the operation method or technique, thereby reducing the damage to the nerve and blood vessels. However, there is no report on the application of multimodal electrophysiological monitoring in the treatment of thoracic tuberculosis through transverse costal process approach and posterior pedicle screw fixation. In this study, 25 patients with thoracic tuberculosis were treated with costal transverse process approach and posterior pedicle screw fixation combined with MIOM. The purposes of this study are as follows: (i) to explore the effect of costal transverse process approach and posterior pedicle screw fixation for thoracic tuberculosis; and (ii) to explore the effect of multi-modal intraoperative electrophysiological monitoring in the costal transverse process approach and posterior pedicle screw fixation for thoracic tuberculosis .

Materials and Methods

Inclusion and Exclusion Criteria

This study investigated patients who underwent multi-modal electrophysiological testing during the rib-transverse approach combined with intraoperative multimodal electrophysiological testing in our hospital between December 2017 and September 2019. All patients provided informed consent.

Inclusion Criteria

The inclusion criteria following PICOS principle were as follows: (i) in accordance with Bone and Joint Tuberculosis[8], patients were diagnosed as thoracic tuberculosis should be based on medical history, clinical manifestations, physical signs, imaging and laboratory examinations; (ii) patients who have undertaken costal transverse process approach combined with intraoperative multimodal nerves electrophysiological monitoring and treatment of thoracic tuberculosis; (iii) observe the changes of SEP, TES-MEP, and EMG waveforms during the operation, and compare the preoperative and postoperative VAS scores, erythrocyte sedimentation rate, Cobb angle, and ODI scores; (iv) clinical and radiological records complete; and (v) the patient has been followed up for at least 1 year.

Exclusion Criteria

The exclusion criteria were as follows: (i) patients with active pulmonary tuberculosis and tuberculosis combined with other sites; (ii) patients with multi-drug resistance; (iii) patients with previous history of upper thoracic spine surgery; (iv) vital organ dysfunction, which is difficult to tolerate surgery; and (v) patients who cannot receive electrical stimulation, including patients with a history of epilepsy, craniocerebral trauma, skull defects, mechanical or electrical instrument pacemaker implantation, cochlear implantation, and deep brain stimulation.

Monitoring Methods

With the US Medtronic (Medtronic NIM-ECLIPSE System) channel intraoperative monitoring system, after induction of anesthesia, we used the quadruple stimulation muscle contraction test (TOF), which can monitor the metabolism of muscle relaxants. The stimulating site was a median nerve. The recording electrode was placed on the great occipital muscle. When the TOF value was >0.7,the paravertebral muscle and paravertebral soft tissue were stripped, and the spine was exposed. The measured TES-MEP and SEP waveforms were used as the baseline. Real-time waveform comparison was detected during key stages such as pedicle screw placement, open correction of kyphosis, vertebral lesion removal, and support for bone grafting. SEP used decay of amplitude ≥50% or prolongation of incubation period ≥10% as the alarm standard[9,10]. TES-MEP used the decrease of amplitude ≥80% or the extension of incubation period ≥10% as the alarm criterion[11,12]. After increasing the stimulation intensity and the waveform had not recovered after multiple stimulations, it was regarded as positive monitoring; if the waveform changes after 10 min, there was still no recovery trend, then we investigated the cause and took corresponding measures. During the monitoring, EMG used the occurrence of continuous burst of EMG as the alert standard of nerve root injury.

Somatosensory Evoked Potential (SEP)

Due to the monitoring of thoracic spine tuberculosis patients, the upper extremity SEP was not routinely monitored. The lower extremity SEP (posterior tibial nerve) was selected and adopted international standards[13]. The anode was placed on the medial malleolus of both feet during stimulation, with the cathode near the proximal end and about 3 cm away from the anode. The subcutaneous screw plug is screwed into the scalp and fixed at FZ,CZ,C3, and C4 points (determined according to the 10/20 lead system established by the International Electroencephalography Society).

Motor Evoked Potential (MEP)

All MEPs used transcranial electrical stimulation, recording electrodes were paired with acupuncture electrodes, and thoracic spine monitoring selected bilateral tibialis anterior muscle, gastrocnemius muscle, flexor abdominis, and rectus femoris muscle as target muscles. Using constant-pressure electrical stimulation, the two spiral electrodes are placed at the C1 and C2 positions, respectively, which are cathode and anode. At the same time, the myoelectric activity of the large or small interocular muscle was recorded.

Electromyography (EMG)

In free EMG monitoring, the recording double needle electrode is placed on the target muscle innervated by the corresponding nerve root on both sides, the recording electrodes are 2 cm apart, the movable electrode is fixed on the abdominal muscle, and the reference electrode is fixed on the tendon. Reflect on the electrical activity of the corresponding innervated muscles after nerve roots are stimulated during surgery in a timely manner.

Surgical Methods

All procedures were performed by the same surgeon, and the specific process was outlined in the following five steps.

Anesthesia Method and Position

The patient was first placed in the supine position. Sufentanil (2–3 μg/kg) and etomidate (0.2–0.3 mg/kg) were used for induction of anesthesia during routine induction of anesthesia, followed by intravenous injection of rocuronium (0.6–0.8 mg/kg) for intubation. No neuromuscular blockers were used thereafter. During the operation, intravenous infusion of remifentanil (0.15–0.20 μg/kg/min) and propofol (4–12 mg/kg/h) was used to maintain anesthesia to facilitate neuroelectrophysiology monitoring[14]. After successful anesthesia, the patient is placed in a prone position.

Exposure and Pinning

Locate the diseased vertebrae in the C-arm fluoroscopy, make an arc-shaped incision about 12 cm inward from the lateral aspect of the costal joint of the diseased vertebrae, cut and strip the skin, deep fascia, and erector spinae in turn, and expose to the bilateral lamina layer by layer and conduct articular processes. Pedicle screws were inserted under multimode electrophysiological monitoring during the operation. The kyphotic deformity is slowly corrected by the pedicle screw rod system, and after the fixation is completed, it is sutured layer by layer to the deep fascia.

Lesion Removal and Spinal Cord Decompression

Tilt the operating table to the opposite side of the incision arc, peel off and expose the costal transverse joint and ribs on the larger side of the lesion, and cut the ribs 8 cm from the posterior midline. When bluntly stripping the upper pleura of the vertebral body, pay attention to protecting the intercostal blood vessels and nerves. Fully expose the lesion, thoroughly remove the necrotic tissue in the lesion under intraoperative multi-mode electrophysiological monitoring until healthy bone wounds appear, and perform spinal cord decompression at the same time.

Support Bone Graft and Pathological Examination

The bone surface of the lesion was trimmed and leveled, the bone defect after removal was measured, and the ribs on the side of the lesion were trimmed to a suitable shape. Support and graft the lesion. Pathological products such as dead bones and cheese-like substances removed during surgery are sent for pathological examination (Fig. 1).

Incision Closure

Finally, isoniazid and streptomycin gelatin sponge were injected into the lesion, a drainage tube was placed at the anterior column lesion and the posterior pedicle screw fixation, and the incision was sutured layer by layer.

Postoperative Treatment

The drainage tube was removed when the drainage volume in the surgical area was <50 mL/day. After resting in bed for 2 weeks, the patient wore a vest and walked out of bed, and gradually resumed normal activities 6 months after the operation. The patients continued the quadruple chemotherapy regimen (isoniazid 0.3 g/day, rifampicin 0.45 g/day, ethambutol 0.75 g/day, pyrazinamide 1.5 g/day) for 18 months. ESR and liver and kidney function were reviewed every week after surgery, and every month after 4 weeks. Films were taken for review 1 week after surgery, and then every 3 months.

Observation Indicators

Visual Analogue Scale (VAS)

The VAS is the most commonly used questionnaire for quantification of pain. It is a continuous scale comprised of a horizontal or vertical line, usually 10 cm in length. For pain intensity, the scale is most commonly anchored by "no pain" (score of 0) and "pain as bad as it could be" (score of 10). A score of 0 is considered as no pain, 1–3 mild pain, 4–6 moderate pain, and 7–10 severe pain.

Oswestry Disability Index (ODI)

Oswestry disability index (ODI) is a principal condition-specific outcome measure used in the management of spinal disorders, and to assess patient progress in routine clinical practice. The ODI score system includes 10 sections: pain intensity, personal care, lifting, walking, sitting, standing, sleeping, sex life, social life, and traveling. For each section of six statements the total score is 5. Intervening statements are scored according to rank. If more than one box is marked in each section, take the highest score. If all 10 sections are completed, the score is calculated as follows: total score out of total possible score × 100. If one section is missed (or not applicable) the score is calculated: (total score/(5 × number of questions answered)) × 100%. A score of 0%–20% is considered mild dysfunction, 21%–40% is moderate dysfunction, 41%–60% is severe dysfunction, and 61%–80% is considered as disability. For cases with a score of 81%–100%, the patient is either long-term bedridden or exaggerating the impact of pain on their life.

Cobb Angle

The angle is formed by making an extension line after destroying the upper edge of the upper vertebral body and

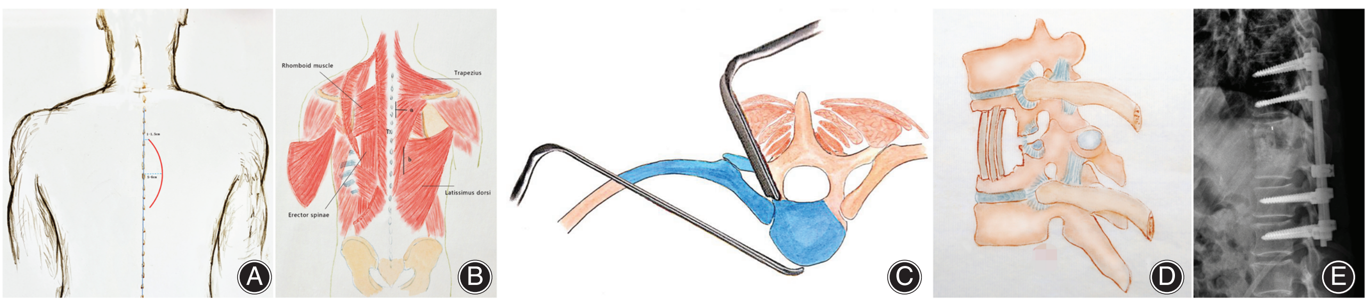

Fig 1 Surgery hand drawing: (A) The incision design for the transverse process of the costal process: an arc-shaped incision about 12 cm long is cut inward from the lateral side of the costal transverse process joint of the diseased vertebrae; (B) the upper thoracic spine is incised in a "T" shape of the trapezius muscle, the lower thoracic spine is pulled inward along the outer edge of the trapezius muscle; (C) the transverse process of the diseased vertebrae and the corresponding segment of 8-10 cm ribs are removed, which can reveal the lesion; (D) thoracic ribs are fused to provide anterior column stability; (E) intraoperative fluoroscopy shows that the posterior approach is fixed in place, and the thoracic anterior column is supported by bone grafting to correct the kyphosis.

the lower edge of the lower vertebral body, and then make two vertical lines, respectively, at the angle between the two vertical lines. End vertebrae refer to the upper and lower vertebrae with the largest kyphosis. Kyphosis Cobb angle <10° is negative, 10°–20° is positive, >20 is obviously positive.

ESR

ESR is a measurement of erythrocyte sedimentation in citrate-diluted blood after 1 h in a 30 cm-long open glass tube installed vertically on a support. Normal reference range: male is 0–15 mm/1 h; female is 0–20 mm/1 h.

Data Analysis

Data Analysis was conducted using SPSS Statistics software (version 25.0, IBM, Armonk, NY, USA). Measurement data were expressed as mean ± standard deviation. Paired t-test was used to determine the difference in measurement data between preoperative and last follow-up. $P < 0.05$ was considered statistically significantly.

Result

Operation Condition

The average operation time was 228.9 ± 20.6 min (range, 180–330 min), The average blood loss during the operation was 255.7 ± 78.8 mL (range, 200–500 mL). There was no injury of great vessels occurring during the operation, no cerebrospinal fluid leakage caused by dural sac tear, and also no death.

Treatment of Intraoperative Monitoring in MIOM

All 25 patients were successfully monitored. A total of 12 patients had intraoperative waveform abnormalities, including seven males and five females. Among them, five cases had abnormal SEP waveform alone, two cases had abnormal MEP waveform alone, and five cases had abnormal MEP accompanied by EMG burst potential. After the abnormal waveform was detected in all patients during the operation, the monitoring waveform recovered after the relative treatment in time.

SEP

There were five patients with abnormal SEP waveform monitoring during the operation, including three males and two females. Three cases were caused by the compression of the spinal cord during the removal of the lesion and the washing process. Timely replacement of disassembly equipment and gestures, and adjustment of the flushing flow, the waveform returned to normal (Fig. 2); one case was caused by a drop in systolic blood pressure, and the waveform returned to normal after timely intensive treatment. In one case, the SEP waveform was abnormal. The operation was suspended for 10 min and then recovered on its own. It did not reappear before the operation.

MEP

There were seven patients with abnormal TES-MEP waveform during the operation, including four males and three females. Five cases occurred in the process of pedicle screw placement. Intraoperative fluoroscopy showed that one case of screw was broken, four cases of screw channel were too close to the inner wall of the pedicle, the nail path was adjusted in time, and the waveform was restored after the nail was repositioned. One case was caused by the tilt of the operating table during the operation, and the waveform gradually recovered after timely adjustment of the tilt angle of the operating table. One case occurred during the correction of the pedicle screw system, on the other side of the operation. After the nail bar correction is completed, the

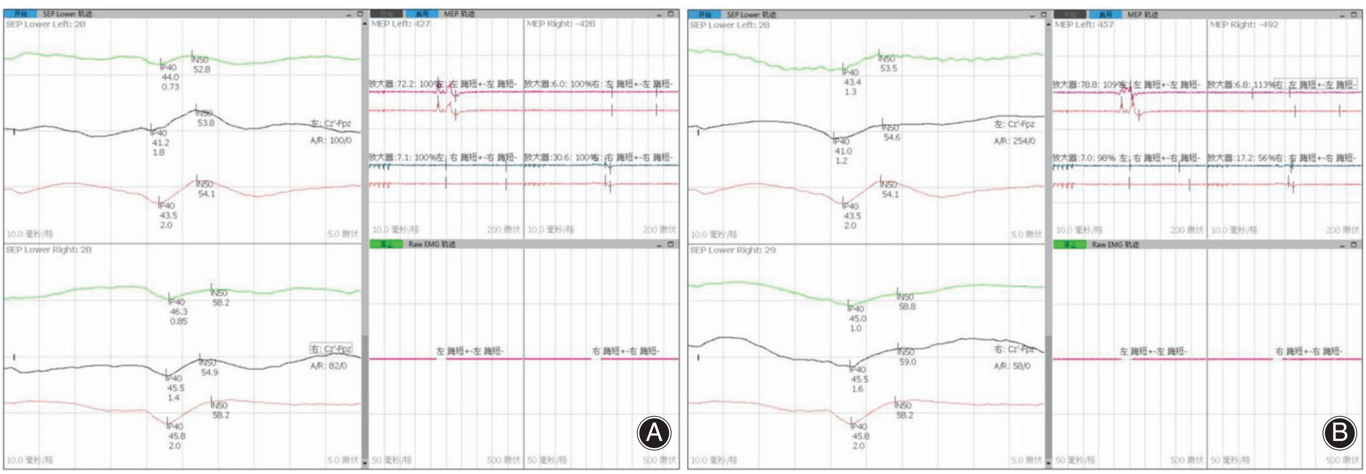

Fig 2 A 20-year-old male patient with tuberculosis of T5-7 was operated on under multimodal neuroelectrophysiological monitoring of transcostal transverse process approach for bone graft removal and posterior vertebral arch fixation. (A) SEP amplitude during intraoperative decompression decreased by more than 50%; (B) after the surgeon was informed and treated in time, the SEP amplitude recovered.

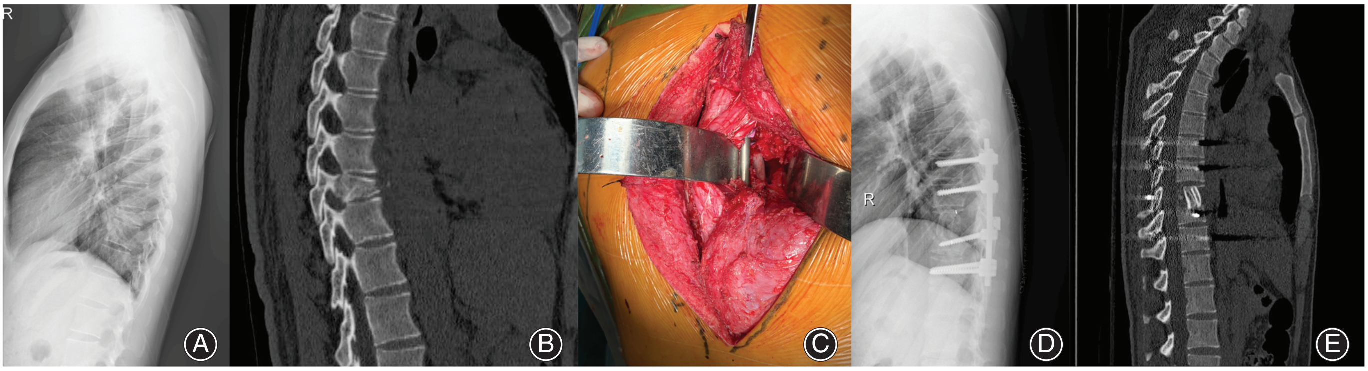

Fig 3 A 26-year-old male patient with tuberculosis of T_{8-9} was operated on under multimodal neuroelectrophysiological monitoring of transcostal transverse process approach for bone graft removal and posterior vertebral arch fixation: (A, B) preoperative thoracic spine X-ray lateral scan and CT reconstruction sagittal radiograph, showing severe destruction of T8-9 vertebral body, wedge deformation, severe kyphosis; (C) during the operation, we used the transcostal transverse process approach to remove the lesion and take the rib for bone grafting; (D, E) postoperative X-ray lateral scan and CT reconstruction sagittal radiographs showed that after the removal of the fixed lesions in the nail-rod system and the fusion of the ribs and bone grafts, the kyphosis deformity was significantly improved, and the physiological curvature and weight-bearing ability were restored.

waveform gradually returns to normal. By the end of the operation, the waveform did not appear abnormal again.

EMG

There were five patients with EMG bursts during the operation, including three males and two females. Five cases had EMG burst potential accompanied by abnormal TES-MEP waveform. After corresponding adjustments during the operation, the EMG burst potential disappeared and no abnormality occurred again.

Clinical Efficacy

Patients were followed up for 12 to 21 months, with an average of 16 months. During follow-up, no loosening, shedding or fracture of internal fixation was found in all patients (Figs 3 and 4). By the last follow-up, all patients had no symptoms of tuberculosis poisoning such as low-grade fever, night sweats, weight loss, and fatigue. The postoperative kyphosis deformities of the patients were restored, and the nerve function was restored. There was no loosening of internal fixation or broken nails. All 25 patients returned to normal activities 12 months after the operation.

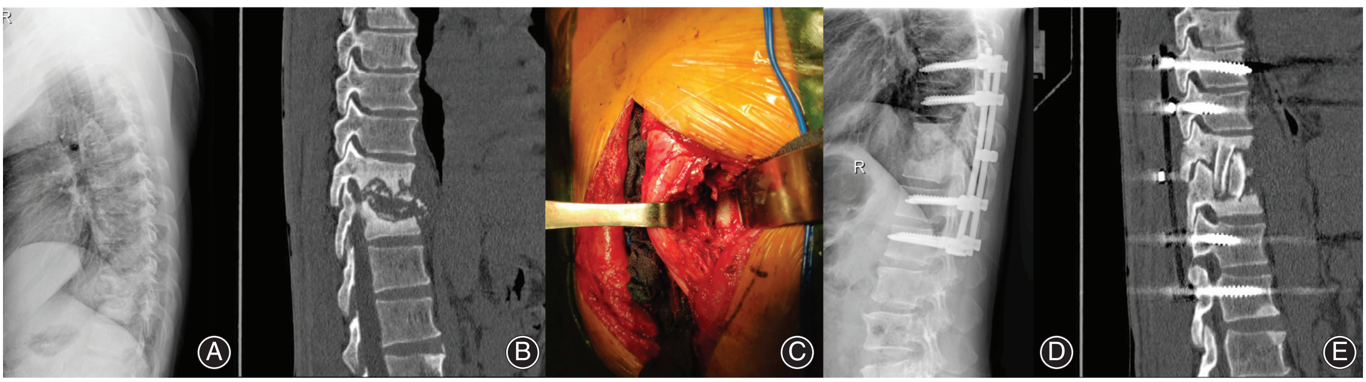

Fig 4 A 50-year-old male patient with tuberculosis of T8-9 was performed operation of multimodal neuroelectrophysiological monitoring of transcostal transverse process approach for bone graft removal and posterior vertebral arch fixation: (A, B) preoperative X-ray lateral radiograph and CT sagittal reconstruction show that T_{11-12} vertebral body osteolytic destruction, intervertebral disc destruction, kyphosis deformity with mild instability; (C) during the operation, we used the transcostal transverse process approach to remove the lesion and take the rib for bone grafting; (D, E) postoperative X-ray lateral position film and CT sagittal reconstruction showed that after the removal of the fixed lesion with the nail-rod system and the fusion of the ribs and bone grafts, the stability of the spine was improved, and the physiological curvature and weight-bearing ability were restored significantly.

TABLE 1 Changes of VAS score, erythrocyte sedimentation rate, Cobb angle and ODI score of patients one week before operation and one year after operation

Variables	One week before surgery	One year after surgery	*P* value
VAS (points)	7.83 ± 1.36	2.48 ± 0.98	0.02
ESR (mm/1h)	46.23 ± 7.59	7.19 ± 3.45	0.01
Cobb angle (°)	28.25 ± 7.26	6.55 ± 2.89	0.01
ODI (%)	83.45 ± 6.94	54.30 ± 6.59	0.03

Note: The VAS score, erythrocyte sedimentation rate, Cobb angle and ODI score indexes all decreased 1 year after operation compared with 1 week before operation; and the differences were statistically significant: $P < 0.05$

Visual Analogue Scale (VAS)

At the last follow-up, the mean VAS score improved from 7.83 ± 1.36 points 1 week before surgery to 2.48 ± 0.98 points at the 1-year follow-up after surgery. It was shown that there was statistical difference ($P = 0.01$) between pre- and post-operation, which illustrated significant pain relief.

Oswestry Disability Index (ODI)

At the last follow-up, the mean ODI score decreased from 83.45% ± 6.94% one week before surgery to 54.30% ± 6.59% at the 1-year follow-up after surgery (Table 1). It was shown that there was statistical difference ($P = 0.03$) pre- and post-operation. The results show that, in our study, the postoperative function of patients with this treatment method was better. Good functional recovery proves the effectiveness of the treatment.

Cobb Angle

At the last follow-up, the mean Cobb angle improved from 28.25° ± 7.26° one week before surgery to 6.55° ± 2.89° at the 1-year follow-up after surgery. It was shown that there was statistical difference ($P = 0.02$) pre-operation and post-operation. This proved that the postoperative kyphosis of the patient was significantly improved.

ESR

At the last follow-up, the mean ESR recovered from 46.23 ± 7.59 mm/1 h 1 week before surgery to 7.49 ± 3.45 mm/1 h at 1-year follow-up after surgery. It was shown that there was statistical difference ($P = 0.01$) between pre-operation and post-operation. The results showed that there were statistical differences before and after surgery, and this treatment effectively removed the lesion and controlled the infection.

Subgroup Analyses

Gender and age have no significant difference in the improvement rate of ODI and Cobb angle after operation (Table 2).

TABLE 2 ODI and Cobb angle improvement in subgrouped patient (mean ± SD)

Group	ODI improvement	Cobb angle improvement
Age		
Age ≥60 years	29.94 ± 16.38	22.02 ± 2.53
<60 years	32.53 ± 14.31	22.46 ± 2.86
P-value	0.85	0.76
Gender		
Male	32.48 ± 14.83	23.45 ± 3.01
Female	30.57 ± 14.88	22.48 ± 2.86
P-value	0.54	0.72

Postoperative Complications

After the operation, none of the patients developed internal fixation loosening and prolapse, worsened kyphosis, increase of erythrocyte sedimentation rate and other infection indicators, recurred lesions or incision sinus formation, or other adverse results.

Discussion

Characteristics of Thoracic Tuberculosis and Common Surgical Methods

Tuberculosis is the second most deadly infectious disease in the world. The World Health Organization (WHO) announced in the "Global Tuberculosis Report 2015"[15] that in 2014, there were approximately 9.6 mn new tuberculosis patients worldwide, resulting in approximately 1.5 mn deaths. Spinal tuberculosis is a common type of extrapulmonary tuberculosis, accounting for about 50% of bone and joint tuberculosis[16], of which thoracic tuberculosis accounts for about 39.6% of spinal tuberculosis[17]. The treatment of thoracic tuberculosis is now usually combined with surgical treatment on the basis of regular chemotherapy, so as to achieve the purpose of eliminating the infected lesion, releasing the compression of the spinal nerve, and correcting the kyphosis. However, there is still a lack of a unified standard surgical method, and how to choose the surgical method is still controversial. Among the many surgical methods, the costal transverse process approach is one of the reliable surgical methods for the treatment of thoracic tuberculosis. The surgical method is through the same skin incision without changing the position during the operation, reducing the amount of bleeding, and destroying the posterior column of the spine; the thoracic lesions cannot be removed. Through the thoracic cavity, interference to the respiratory and circulatory system is avoided, the thoracic cavity contamination is avoided, and the postoperative complications are reduced. The posterior pedicle screw is implanted through the uninvaded pedicle to avoid the spread of infection due to internal fixation, and multi-end fixation is feasible to correct kyphotic deformity, which is stronger than anterior fixation, and the removal of internal fixation is relatively convenient. Taking the physiological arc and thoracic kyphosis close to the ribs as a support bone graft can prevent the bone graft from slipping and absorption. At the same time, the occurrence of donor site complications such as iliac bone grafting is avoided. However, due to the anatomy of the thoracic spine, the front of it contains the heart, the mediastinum, and the left and right lungs. The surrounding vertebral body is adjacent to important structures such as the thoracic aorta, inferior vena cava, spinal cord, and nerve roots. The pedicle of thoracic vertebra is thin and hormone pulse therapy is forbidden for tuberculosis patients. It may cause serious complications such as spinal cord and nerve root injury, aortic injury, and cerebrospinal fluid leakage when the nail is fixed, the lesion is removed, and the bone is grafted[18]. It is necessary to monitor the function of the spinal cord and nerve roots to reduce the damage to the nerves and blood vessels and other important tissues during the operation. Therefore, our hospital adopts intraoperative multi-mode neuroelectrophysiological monitoring during the transcostal and transverse process approach and posterior vertebral arch internal fixation for thoracic tuberculosis patients, which reduces the mechanical traction, compression, and thermal damage during the operation. Damage to the spinal cord and nerve heel.

Advantages of Multi-modal Neuroelectrophysiological Monitoring used in Spinal Tuberculosis Surgery

With the development of neuroelectrophysiological detection technology and the popularization of concepts in recent years, more and more spine surgeons use it as an important technical means to improve the safety, quality of spinal surgery, and postoperative satisfaction of patients. Among them, SEP is a method to assess the state of nerve function by placing recording electrodes on the sensory nerve conduction pathway and analyzing the amplitude and latency of the signal waveform generated after peripheral nerve stimulation. It is easy to obtain monitoring graphics and is an indicator to judge the degree of spinal cord injury objectively. Stimulation during SEP monitoring will not affect the patient's motion system, and continuous monitoring will not cause the patient's muscle movement to interfere with intraoperative operations, and it is not affected by muscle relaxants and is widely used[19]. However, because SEP mainly detects sensory conduction function, it takes a certain amount of time to superimpose it. It is difficult to monitor SEP alone during surgery to reflect the state of spinal cord function, especially spinal cord motor function. The SEP monitoring results are easily affected by factors such as mechanical compression, ischemia, temperature, and hypotension. SEP can only indirectly reflect the motor function of the spinal cord and it is not comprehensive, and the specificity of nerve root function monitoring is poor. Monitoring simple spinal cord motor nerve injury patients is prone to false negative results[20].

TES-MEP places recording electrodes on the target muscles corresponding to the electrical stimulation of the cerebral cortex to analyze and judge the motor function status of the spinal cord and the integrity of the conduction pathway. Directly monitor the spinal cord motor nerve by reflecting the motor conduction state of the anterior cord and lateral cord. MEP has high sensitivity and high specificity for monitoring spinal nerve function. MEP intraoperative monitoring can provide sensitive, timely, and stable feedback on the state of intraoperative motor nerve function and conduction pathways, and accurately reflect various intraoperative factors that cause spinal cord motor nerve function damage, so that the surgeon can remove the harm in time factor. The waveform of the monitoring signal is stable, the recording does not need to be superimposed, and the waveform can be obtained with only a single stimulation during the operation[21,22]. MEP can selectively monitor the motion conduction pathway, and a warning message can appear 5 min earlier than SEP. In addition, MEP is less affected by hypothermia and hypotension. Compared with SEP, it can still be monitored relatively accurately in the presence of spinal cord ischemia. However, MEP only provides feedback after the spinal cord nerve function is damaged and does not have an early warning effect, so errors may occur due to poor resolution of weaker signals. At the same time, due to the susceptibility to muscle relaxants, the preoperative patient's motor function evaluation, anesthesia induction and quadruple stimulation muscle contraction tests need to be strictly controlled[23]. In addition, because MEP detection of electrical stimulation can easily cause tremor in patients after anesthesia, interfere with the operation of the surgeon, and even cause iatrogenic spinal cord injury. When using MEP, electrical stimulation and electrical coagulation burns can induce seizures, cardiovascular system changes, spinal dural complications, and hidden dangers such as intraoperative muscle movement[24,25].

EMG refers to the action potential induced by the contraction of the muscles innervated by specific nerve fibers that innervate a certain muscle group by mechanical or electrical stimulation. Intraoperative monitoring of myoelectric activity can provide feedback on the functional state of nerve roots through indirect reflection. After nerve damage occurs, it can be processed in time to avoid nerve root damage caused by intraoperative operations. EMG monitors target muscle EMG activity with real-time and high sensitivity characteristics, and continuous monitoring is feasible[26]. When the thoracic tuberculosis pedicle screw is placed and the lesion is removed, when the traction or screw penetrates the pedicle wall and is close to the nerve root, clamping nerve and accessory structure, the burst waveform can be detected, and the surgeon can check There are operations to adjust. It has a good effect on the monitoring of nerve root function, but it cannot monitor the intraoperative spinal cord function.

The ideal intraoperative electrophysiological monitoring should provide comprehensive, direct, and accurate monitoring information for the spinal cord and nerve roots. Many scholars recommend the use of multi-mode neuroelectrophysiological testing (MIOM)[27–29], a technology that combines multiple monitoring modes of SEP, TES-MEP, and EMG, and comprehensively uses multiple monitoring methods to assess the functional status of the spinal cord and nerve roots. The electrophysiological detection technology of the integrity of the conduction pathway can combine the advantages of each monitoring mode to improve the sensitivity and accuracy of intraoperative monitoring. The three modes complement each other and provide the surgeon with a timely and comprehensive sensory, motor nervous system, and nerve root function status during the operation under anesthesia[30]. In this way, the shortcomings and deficiencies of the single detection mode used in the operation are avoided[31], and the potential or formed spinal cord and nerve root injuries can be timely and accurately treated. It plays an important role in spinal surgery, especially thoracic surgery.

In this group of 25 surgical patients, five patients had abnormal SEP waveform during operation, eight patients had abnormal TES-MEP waveform, and five patients had abnormal TES-MEP waveform during pedicle screw placement, and EMG was detected at the same time. Burst potential. During the operation, abnormal electrophysiological monitoring was successfully monitored and promptly reminded the surgeon to adjust accordingly. After the emergency treatment during the operation, the waveform was successfully restored to normal, which avoided the damage to the patient's nerve function during the operation. The postoperative erythrocyte sedimentation rate and VAS scores of the patients were lower than those before the operation, and the difference was statistically significant. According to the comparison of the Cobb angle and ODI scores of the patients before and after the operation, the postoperative kyphosis and function of the patients were significant compared with those before the operation. The observation results of this group show that the multi-mode neuroelectrophysiological detection improves the safety of intraoperative operations, avoids serious surgical complications, and increases the success rate of surgery and patient satisfaction while adopting appropriate surgical methods.

Limitation of the Study

Although our initial results are promising, there are several limitations and unanswered questions. First, this study only summarized the effect of the transverse costal process approach combined with multi-mode intraoperative electrophysiological monitoring in the treatment of thoracic tuberculosis, but did not compare with the simple costal transverse process approach. For the next step, a control group should be set up, and the variate analysis of functional outcomes should be further investigated so as to better illustrate the advantages of our method. Secondly, our study has a short follow-up period and the number of patients in the series is limited. Further prospective designed studies with large sample size are required to further verify the treatment effect.

Conclusion

To sum up, for thoracic tuberculosis patients with complex anatomical structures undergoing cost-transverse process approach, neuroelectrophysiological testing can determine the damage of spinal cord and nerve root function early, stop the operation in time, and give targeted intervention measures. It can minimize the nerve damage of the nervous system during and after the operation, and improve the satisfaction of patients after recovery. Single-mode neuroelectrophysiological testing exists, and needs to be superimposed on time, temperature, and blood flow, which will have a large impact. It cannot provide early warning of spinal cord nerve function damage, which will result in untimely and incomplete feedback on the detection effect. Multi-mode neuroelectrophysiological monitoring (MIOM) combines multiple monitoring techniques to assess the integrity of spinal cord and nerve root function and conduction pathways, making full use of the advantages of each monitoring mode, and reducing the impact of errors caused by the lack of a single detection mode on surgery. This greatly improves the accuracy and sensitivity of intraoperative monitoring. In clinical application, it can reduce spinal cord and nerve root damage, greatly improve patient satisfaction and clinical efficacy, and has great clinical promotion value.

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