Monopolar-probe monitoring during spinal surgery with expandable prosthetic ribs

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Abstract :

Background: Intraoperative monitoring (IOM) has been proven to decrease the risk of neurological injury during scoliosis surgery. The vertical expandable prosthetic titanium rib (VEPTR) is a device that allows spinal growth. However, injuries to the spinal cord and brachial plexus have been reported after VEPTR implantation in 2 and 5% of patients, respectively. Simultaneous monitoring of these two structures requires the use of multiple time-consuming and complex methods that are ill-suited to the requirements of paediatric surgery, particularly when repeated VEPTR lengthening procedures are needed. We developed a monopolar stimulation method derived from Owen's monitoring technique. This method is easy to implement, requires only widely available equipment, and allows concomitant monitoring of the spinal cord and brachial plexus. The primary objective of this study was to assess the reliability of our technique for brachial plexus monitoring by comparing the stability of neurogenic mixed evoked potentials (NMEPs) at the upper and lower limbs.

Hypothesis: We hypothesised that the coefficients of variation (CVs) of NMEPs were the same at the upper and lower limbs.

Material and methods: Twelve VEPTR procedures performed in 6 patients between 1st January 2012 and 1st September 2014 were monitored using a monopolar stimulating probe. NMEPs were recorded simultaneously at the upper and lower limbs, at intervals of 150 s. The recording sites were the elbow over the ulnar nerve and the popliteal fossa near the sciatic nerve. Wilcoxon's test for paired data was used to compare CVs of the upper and lower limb NMEPs on the same side.

Results: Mean CV of NMEP amplitude at the lower limbs was 16.34% on the right and 16.67% on the left; corresponding values for the upper limbs were 18.30 and 19.75%, respectively. Mean CVs of NMEP latencies at the lower limbs were 1.31% on the right and 1.19% on the left; corresponding values for the upper limbs were 1.96 and 1.73%. The risk of type I error for a significant difference between the upper and lower limbs was 0.5843 on the right and 0.7312 on the left for NMEP amplitudes and 0.7618 on the right and 0.4987 on the left for NMEP latencies.

Conclusion: Using an epidural active electrode and a sternal return electrode allows simultaneous stimulation of the cervical spinal cord and brachial plexus roots. The NMEPs thus obtained are as stable (reliable) at the upper limbs as at the lower limbs. This easy-to-implement method allows simultaneous monitoring of the upper and lower limbs. It seems well suited to VEPTR procedures.

Level of evidence: IV, retrospective single-centre non-randomised study.

Keywords : Monitoring, Intraoperative, Scoliosis, Paediatric patients, Evoked potentials, Motor

Introduction

The vertical expandable prosthetic titanium rib (VEPTR) has a well-established role in spinal surgery for growing children who have thoracic insufficiency syndrome with spinal deformities or multiple fused ribs [1]. Thoracic outlet syndrome and spinal cord compression are the two main complications reported after VEPTR. implantation. The brachial plexus may be injured either directly or by compression between the rib cage and the clavicle or proximal humerus. Somatosensory evoked potentials (SEPs), motor evoked potentials elicited by transcranial electrical stimulation (tcMEPs), and neurogenic mixed evoked potentials (NMEPs) are the most widely used parameters for assessing the somatosensory and motor pathways of the spinal cord. Intraoperative monitoring (IOM) of the brachial plexus usually relies on SEPs; tcMEPs; or continuous, spontaneous or stimulated electromyography [2–4]. Simultaneous IOM of the spinal cord and brachial plexus requires a combination of techniques whose time-consuming and complex implementation is ill-suited to the conditions of surgery and anaesthesia in young children, particularly during revision surgery to provide further lengthening. We describe a method derived from the technique described by Owen et al. [5]. Direct stimulation is applied at two sites, one at the cervical spinal cord and the other at the brachial plexus roots, to allow simultaneous IOM of these two structures. We developed a monopolar device that delivers low-level current to the brachial plexus roots, thus allowing the recording of upper limb NMEPs with only minimal electrical artefacts. Here, our primary objective was to assess the reliability of this monopolar stimulation method for brachial plexus IOM.

Material and methods

IOM with monopolar-probe monitoring was used for 12 procedures performed in 6 patients between 1st January 2012 and 1st September 2014. We use the Keypoint® 4.2 System (Medtronic, Minneapolis, MN, USA), a commercially available IOM device that complies with the European Union standards. The active electrode delivers electrical stimulations no greater than 100 mA in intensity. The only differences with the conventional IOM method were the type of electrode and position of the return electrode. Whereas conventional epidural stimulation relies on a pair of needle-electrodes, we used a single epidural needle-electrode and a sternal grounding pad. Before the patient was turned in the prone position on the operating table, a wide conductive adhesive pad electrode was applied on the sternal manubrium and connected to the return electrode of the stimulating device. We used 3MTM Series 9160 electrodes (3M Healthcare, St Paul, MN, USA), which usually serve as grounding pads for electric scalpels. Before performing the incision, the surgeon inserted the epidural needle-electrode at C7–T1 down to the ligamentum flavum and connected it to the stimulator. NMEP quality was assessed before starting the surgical procedure. NMEPs were recorded via pairs of subcutaneous electrodes inserted on each side of the patient, in the popliteal fossa near the sciatic nerve at the lower limbs and in the epicondylar groove of the elbow near the ulnar nerve at the upper limbs. Each NMEP was computed as the mean of 50 stimulations at 3.7 Hz with a 1-ms long rectangular current on a 30- to 3000-Hz bandpass. Mean current intensity producing a supramaximal response was 30 to 50 mA at the lower limbs and 10 to 30 mA at the upper limbs. NMEP amplitude (difference between the positive and negative peaks) and latency were recorded at 150-s intervals, first at the upper limbs and second at the lower limbs with no time delay to minimise response variations related to surgical manipulations. All patients received prophylactic antibiotic therapy with cefazoline, together with tranexamic acid to decrease the bleeding risk. Heart

rate was recorded continuously via pulse oximeter photoplethysmography, as electrical stimulation induces artefacts in electrocardiogram recordings. Also recorded continuously throughout surgery were arterial oxygen saturation (SaO2), blood pressure, and respiratory rate. General anaesthesia was induced with propofol and remifentanil then maintained via inhalation of the halogenated ether sevoflurane in a minimal alveolar concentration (MAC) of 1 or 2, with a mixture of 60% nitrous oxide and 40% oxygen. Neuromuscular blockade was maintained using cisatracurium (1 mg/kg/h). Analgesia was achieved by combining epidural morphine (10 □g/kg/d) and a continuous infusion of remifentanil (0.1–0.2 □g·kg−1·min−1). Halogenated ether inhalation and neuromuscular blockade were not used in patients with myopathy. Magnetic resonance imaging of the spinal cord was performed routinely to look for spinal cord birth defects. Pre-operatively, tcMEPs and lower limb SEPs were analysed to check that IOM would be feasible.

Statistical analysis

Pearson's coefficient of variation (CV) is defined as the ratio of the standard deviation (SD) over the mean (M) of a random variable: CV = SD/M. This dimensionless parameter serves to compare the dispersion of variables having different physical dimensions or different value scales. The CV is used in quality-control procedures in the industry and in analysis laboratories, as well as in cardiac physiology to assess R–R interval variability. Kim et al. [6] suggested using the CV to compare the stability of MEPs recorded with various levels of neuromuscular blockade. To evaluate the stability of upper limb NMEPs obtained using our monopolar IOM method, we compared NMEPs at the upper and lower limbs. The reliability of lower limb NMEPs for spinal cord IOM is firmly established. Given the lack of evidence that NMEPs are normally distributed [7–9], we chose the non-parametric Wilcoxon's test for paired data to compare same side upper limb and lower limb NMEPs.

Results

Mean patient age was 7.2 years (range, 6.1–7.9 years) at first VEPTR implantation. The male-to-female ratio was 0.77/1. In addition to congenital spinal and rib defects, many patients had congenital cardiac and neurological abnormalities (Table 1). Mean CVs were about 15% for NMEP amplitude and 1% for NMEP latency. Wilcoxon's test for paired data showed no significant differences for NEMPs at the upper versus lower limbs (Tables 2 and 3). NMEP amplitude at the right upper limb dropped sharply in 1 patient. An alert was issued, the threshold being a 40% amplitude decrease compared to the response recorded at the start of surgery. There was a marked difference between the right and left sides, ruling out defective stimulation (often due to needle-electrode displacement during surgical manipulations). Compression of the brachial plexus was therefore suspected. Lifting the distraction was followed by full NMEP amplitude recovery (Figs. 1 and 2).

Discussion

To our knowledge, this study provides the first evidence that simultaneous IOM of the brachial plexuses and spinal cord can be achieved using a single stimulation site. This last point considerably simplifies the IOM procedure. Comparisons of CV values established that stability was similar for the lower limb NMEPs recorded using the conventional spinal cord monitoring method and the upper limb NMEPs recorded using our novel monopolar method. Our monopolar stimulator has a single active needle-electrode, which the surgeon inserts at

C7–T1 down to the ligamentum flavum, and a grounding pad, which is applied to the sternum
before the patient is positioned on the operating table. This ‘epidural needle-sternal grounding pad’ set-up allows deep stimulation of both the spinal cord and the ventral and dorsal brachial plexus roots, which is difficult to achieve using the conventional ‘dual epidural needle set-up’. The risk of brachial plexus and spinal cord injury during VEPTR implantation is now firmly established. In a US multicentre prospective study of 1736 VEPTR procedures (327 primary device implantations, 224 device exchanges, and 1185 device lengthenings) in 299 children, Skaggs et al. identified 8 patients with neurological injuries (5 after primary implantation and 3 after device exchange), of whom six had upper limb deficits, including 1 with persistent symptoms after 4 years [10]. Positional nerve injury can occur during a variety of surgical procedures. Their frequency has been estimated at 0.14%, with 38% of cases involving the brachial plexus [11]. They are most common after spinal or heart surgery. Brachial plexus injury is more common when the patient is in the prone position, particularly with the arms
abducted at 90◦ [12,13]. Obesity, diabetes mellitus, and male gender are well-established risk factors. In a retrospective study of 434 procedures, Labrom et al. [14] identified 6.2% of cases of intraoperative brachial plexus injury revealed by an at least 30% decrease in SEPs obtained by ulnar nerve stimulation; 2 cases failed to resolve despite re-positioning of the upper limb, and 1 patient had brachial plexus palsy upon awakening. SEP and tcMEP monitoring are the most widely used methods for VEPTR implantation [14,15]. A drawback of these methods is their sensitivity to anaesthesia, particularly of tcMEPs to inhaled halogenated ethers, which requires specifically designed anaesthesia protocols [16–20]. Furthermore, abnormalities present in addition to the spinal abnormalities, such as cerebral palsy and myopathy, may preclude the use of SEP or tcMEP monitoring. In a prospective study of 103 patients scheduled for spinal surgery and assessed pre-operatively by magnetic stimulation, IOM was not feasible in 33% of patients without MEPs and in 100% of patients with neither MEPs nor SEPs pre-operatively [21]. The high-frequency electrical currents needed for tcMEP recording can induce seizures, with a frequency estimated at 0.03%. A few cases of cardiac arrhythmia have been reported. Transcranial electrical stimulation is contraindicated or requires special precautions in patients with epilepsy, cortical brain lesions, a skull flap, intracerebral vascular clips, heart disease, a pacemaker, or any type of implanted bioelectrical device [22,23]. In our study, the absence of a significant difference in CVs for NMEPs at the upper versus the lower limbs may be ascribable to the small sample size and to the use of non-parametric statistical tests.

Advantages of using a single needle-electrode placed outside the surgical field are listed below:

- NMEP quality can be assessed after anaesthesia induction and before creating the incision.This advantage is valuable when preoperative testing is difficult, for instance because of behavioural disorders;
- the device takes up less space in the operating field;
- the risk of inadvertent needle-electrode displacement is decreased and NMEP stability improved;
- there is no risk of defective stimulation due to electrical current-fluid bridging between the return and active electrodes, a problem frequently reported with conventional NMEP recording;

- responses can be monitored continuously throughout the surgical procedure, particularly during the crucial derotation phase.

The most common drawbacks of our monopolar monitoring method are indicated below:

- percutaneous electrode insertion may prove difficult;
- overweight patients require a needle-electrode that is sufficiently rigid and measures at least 50 mm in length;
- there may be a need for high stimulation intensities, which generate artefacts on ECG monitoring devices but have no adverse physiological effects;
- the method must be modified in patients with contraindications to neuromuscular blockade, of which myopathy is the most common. In this situation, we monitor the muscle motor potentials, at the abductor digiti minimi for the upper limbs and tibialis anterior at the lower limbs. To ensure patient safety, the surgical procedures must be perfectly coordinated with the muscle contractions produced by the spinal cord stimulations. The frequency of the electrical impulses is decreased to 1 Hz and the number of impulses to 5 (the signal-to-noise ratio remains good, as the muscle response amplitude is about 1000 times the amplitude of responses recorded at a peripheral nerve). In contrast to tcMEP monitoring, there is no risk of tongue bite injury, since the trigeminal nerve is not stimulated. There is a relative contraindication in patients with pacemakers.

Our novel technique proved safe. Major electrocardiographic artefacts occur, but the sternal grounding pad does not affect the heart rate values recorded by pulse oximeter photoplethysmography. Neither is there any change in blood pressure values. The electrical field generated by our needle-pad set-up is conical, with high-density currents concentrated on the spine at the tip of the cone and low-density currents over the manubrium at its base. The amount of energy delivered by the stimulation is probably less than 10 Joules. Interestingly, low-level electrical currents (~20 mA) are sufficient to elicit supramaximal responses at the upper limbs. This fact may be ascribable to the anterior-to-posterior direction of the electrical fields and to the proximity of the brachial plexus roots.

Conclusion

Paediatric spinal surgery requires specific IOM techniques. Our work established that monopolar stimulation allows simultaneous IOM of the upper and lower limbs. The set-up time is considerably shorter than with conventional methods. Thus, our novel technique seems well suited to spinal surgery in young children who require repeated anaesthesia to lengthen the spinal growth system without spinal fusion.

Disclosure of interest : the authors declare that they have no conflicts of interest concerning this article.

Table 1
General characteristics of the 6 patients.

Patient	Age at first implantation (years)	Sex	Congenital skeletal defects	Other congenital defects	Cause
TV	4.9	M	Spondylocostal dysostosis		Jarcho-Lévin syndrome
AC	8.3	F	Spondylocostal dysostosis + costal fusion	Dextrocardia	?
KL	6.5	F	Hemivertebrae + costal fusion	Atrial septal defect	?
LB	6.0	M	Vertebral fusion + costal synostosis	Diastematomyelia + meningocele	?
MR	6.8	M		Congenital diaphragmatic hernia	16p11.2 deletion + 13q14.13 duplication
LR	10.9	F	Severe spinal curvature >90◦	Cleft lip and palate + cerebral ventricle hypoplasia	?

Table 2
Mean coefficient of variation for neurogenic mixed evoked potential latencies and comparison of upper and lower limbs using the Wilcoxon's rank sum test.

Side	Lower limbs (%)	Upper limbs (%)	Rank sum	P-value
Right	1.31	1.96	47	0.5843
Left	1.19	1.73	56	0.7312

Table 3
Mean coefficient of variation for neurogenic mixed evoked potential amplitudes and comparison of upper and lower limbs using the Wilcoxon's rank sum test.

Side	Lower limbs (%)	Upper limbs (%)	Rank sum	P-value
Right	16.34	18.30	53	0.7618
Left	16.67	19.75	45	0.4987

Fig. 1. Adverse event in the right upper limb during the distraction procedure, with a good then recovered totally after an alert by the neurophysiologist and promoted the surgeon outcome. Neurogenic mixed evoked potential (NMEP) amplitude dropped sharply to lift the distraction applied by the vertical expandable prosthetic titanium rib.

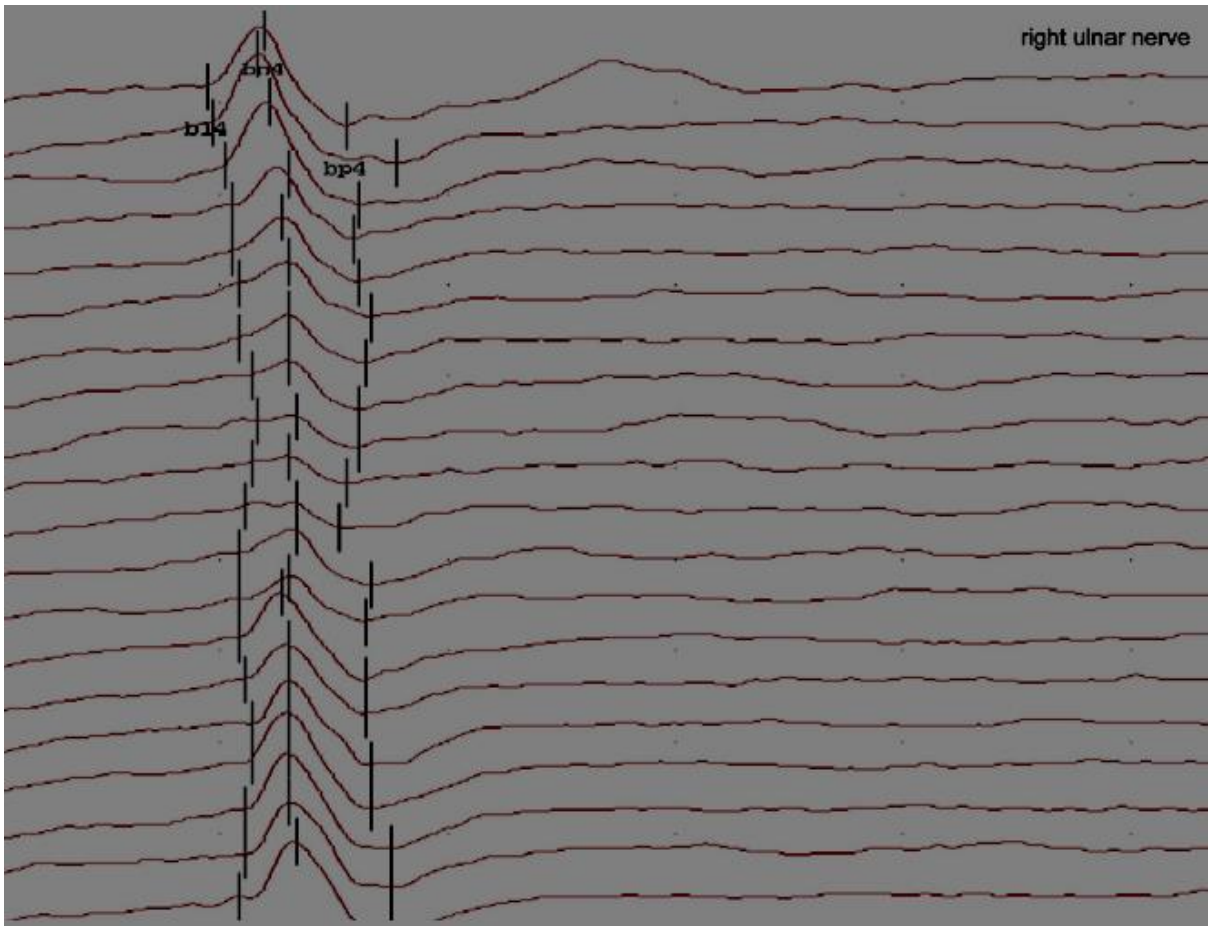

Fig. 2. Graph of the relative neurogenic mixed evoked potentials (NMEP) from the right the right and left sides does not support failure of stimulation (usually due to needle-electrode and left ulnar nerves throughout intraoperative monitoring. The difference between displacement). This difference strongly suggests brachial plexus compression.

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