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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.

1. 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

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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.

2. 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 3M™ 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 (SaO_2), 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 μg/kg/d) and a continuous infusion of remifentanil ($0.1–0.2\ \mu g{\cdot}kg^{-1}{\cdot}min^{-1}$). 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.

2.1. 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.

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	?