Clinical Neurophysiology 117 (2006) 2093–2101
www.elsevier.com/locate/clinph

Monitoring of scoliosis surgery with epidurally recorded motor evoked potentials (D wave) revealed false results

S. Ulkatan [a,*], M. Neuwirth [b], F. Bitan [b], C. Minardi [a], A. Kokoszka [b], V. Deletis [a]

[a] *Hyman-Newman Institute for Neurology and Neurosurgery, Beth Israel Medical Center – Singer Division, 170 East End Avenue, Room 311, New York, NY 10128, USA*

[b] *Spine Institute, Beth Israel Medical Center – Phillips Ambulatory Care Center, New York, NY 10003, USA*

Accepted 22 May 2006
Available online 17 July 2006

Abstract

Objective: To elucidate the mechanism behind D wave amplitude changes after surgical correction of scoliosis.
Methods: We collected D wave and muscle MEP data from 93 patients (78 female, 15 male, age range 4–19 years, mean age 15.9 years), who underwent surgical correction of scoliosis. D waves were recorded via a catheter electrode inserted epidurally through the flavectomy. Muscle MEPs from lower limb muscles were also recorded. Muscle MEPs/D wave were elicited by short trains/single transcranial electrical stimuli. SEPs were elicited through bilateral percutaneous stimulation of the tibial nerves at the ankle and an averaged response from 100 to 200 single sweeps were recorded over the scalp at Cz'/Fz.
In addition, we analyzed intraoperatively obtained X-ray images of the spine in 9 patients and preoperative spinal MRI in two of those nine.
Results: After surgical correction of scoliosis in 25 of 93 (27%) patients, the D wave amplitude changed by more than 20% of its baseline value. A decremental change occurred in 21 (84%) and an incremental change in 4 (16%) patients. D wave decrements of more than 50% were observed in 5 patients without significant SEP changes in any of these cases. In 9 patients, intraoperatively obtained X-rays of the spine (before and after correction of spine curvature) showed no catheter displacement. Muscle MEPs did not change and postoperative sensory-motor status was normal. In 2 patients, preoperative MRI revealed displacement of the spinal cord towards the concave side of the scoliotic curvature.
Conclusions: During scoliosis surgery, D wave amplitude changes should be interpreted cautiously until the definitive cause(s) of these changes are found. One possible mechanism to explain D wave changes during scoliosis correction could involve rotation of the spinal cord within the spinal canal, and the relative position of the epidural recording catheter (ERC). Rotation of the spinal cord after correction of scoliosis could introduce a new relationship between the ERC and the corticospinal tracts (CTs). Due to high incidence of false D wave amplitude changes we suggest that this methodology should not be used to assess the functional integrity of the CTs during scoliosis surgery.
Significance: This study provides new insight into the methodology of D wave monitoring as well as strong evidence of a high incidence of false positive results using D wave monitoring during surgical correction of scoliosis.

Keywords: D wave; Motor evoked potentials; Scoliosis surgery; Intra operative monitoring

1. Introduction

Idiopathic scoliosis is defined as the structural lateral curvature of the spine in healthy children. Correction and stabilization by orthopedic surgery has been the only definitive treatment for severe cases. Intraoperative monitoring

* Corresponding author. Present address: Institute for Neurology and Neurosurgery, Suite 11G-78, St. Luke's /Roosevelt Hospital, 1000 10th Avenue, New York, NY 10019, USA. Tel.: +1 212 636 3282; fax: +1 212 636 3159.
E-mail address: sulkatan@chp.org (S. Ulkatan).

1388-2457/$32.00 © 2006 Published by Elsevier Ireland Ltd. on behalf of International Federation of Clinical Neurophysiology.
doi:10.1016/j.clinph.2006.05.021

(IOM) is an important tool that helps prevent neurologic complications associated with scoliosis surgery (Dawson et al., 1991; Nuwer et al., 1995). Although different IOM methodologies have been used during scoliosis surgery in the past, somatosensory evoked potentials (SEPs) continue to remain the most widely used. Unfortunately, previous research has shown that SEPs do not assess the spinal motor pathways (Ginsburg et al., 1985; Pelosi et al., 1999; Minahan et al., 2001; Jones et al., 2003), and that the combination of muscle MEPs and SEPs represent a superior means of monitoring when compared to single modality techniques (Pelosi et al., 2002; MacDonald et al., 2003).

In 1954, Patton and Amassian first described the methodology for D wave recording following electrical stimulation of the motor cortex in the monkey (Patton and Amassian, 1954). The D wave was interpreted as direct activation of corticospinal tracts followed by one or more indirect (synaptic) activations, recorded as an I wave(s). This methodology has been successfully applied in the operating room (Boyd et al., 1986; Katayama et al., 1988; Burke and Hicks, 1998; Deletis, 1993). Intraoperative variations of 10% in single D wave recordings has been considered to be within acceptable physiological limits (Burke et al., 1995). The same group reported that more than a 20% change in D wave amplitude in averaged recordings should be considered to be a warning sign (Burke and Hicks, 1998). Furthermore it has been shown that during surgery for intramedullary spinal cord tumors, intraoperatively recorded D wave amplitudes closely correlate with postoperative neurological outcome (Morota et al., 1997; Kothbauer et al., 1997, 1998). During supratentorial surgeries, Yamamoto et al. found a similar correlation between D wave amplitude and postoperative neurological outcome (Yamamoto et al., 2004).

D wave recording has been proposed as an effective monitoring modality in scoliosis surgery (Burke et al., 1995). However, there are no reports in the literature showing false results using the D wave.

2. Patients and methods

We analyzed neurophysiological data from 93 consecutive patients with idiopathic scoliosis who underwent corrective surgery by the same orthopedic team from 2001 to 2004 (78 female, 15 male; 4–19 years age range; mean age 15.9 years). Patients underwent routine pre- and postoperative neurological exams which included motor strength, sensory status and tendon reflexes. The patients' parents or legal guardian gave their consent for intraoperative monitoring at the same time as consent to carry out surgery was obtained.

In addition, we evaluated patients' radiological images. Out of 25 patients with significant D wave amplitude changes of more than 20%, 9 had intraoperative X-ray images of the spine (before and after scoliosis correction). Of those 9, only 2 patients had a preoperative spinal MRI. In 6 patients, we also compared D wave amplitudes recorded from epidural recording catheter (ERC), cranially and caudally to the scoliotic curve. Of these 6, 1 patient had intraoperative X-ray images.

Anesthesia was maintained with Propofol (100–150 µg/kg/min) and Fentanyl (1–1.5 µg/kg). A short-acting muscle relaxant (Rocuronium 50 mg/kg) was administered for intubation purposes only. The anesthesia regimen, blood pressure and temperature were kept constant throughout the surgery. Recovery from muscle relaxation was monitored by the train-of-four technique and recorded from the abductor pollicis brevis muscle after stimulation of the median nerve at the wrist.

D wave and muscle MEPs were elicited by transcranial electrical stimulation (TES) delivered through corkscrew electrodes (CS Electrode Nicolet Co., Madison WI, USA) applied over the scalp at C1/C2 (Fig. 1). We used a single stimulus (for eliciting the D wave) or multi pulse stimuli (5–7 stimuli) of 0.5 ms duration with ISI of 4 ms and train repetition rate 2 Hz for eliciting muscle MEPs. The maximum stimulation intensity used in this study was 200 mA delivered from a custom-made constant current stimulator controlled by specialized software. We used intensities of TES which produced the maximum amplitude of the D wave without further shortening of latency and kept that intensity constant until the end of the surgery. This stimulation intensity elicited muscle MEPs in all extremities.

Ten single D waves were averaged and their amplitudes were measured from the first negative to the second

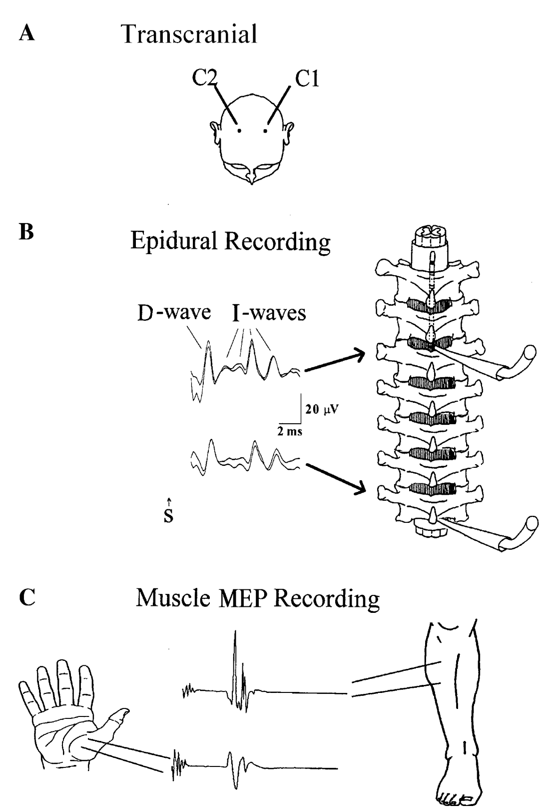

Fig. 1. Schematic illustration of transcranial stimulation (A), D wave, I waves (B) and muscle MEP recordings (C).