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Clinical Study

Intraoperative monitoring during decompression of the spinal cord and spinal nerves using transcranial motor-evoked potentials: The law of twenty percent

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ABSTRACT

Motor-evoked potential (MEP) monitoring was performed during 196 consecutive spinal (79 cervical and 117 lumbar) surgeries for the decompression of compressive spinal and spinal nerve diseases. MEP monitoring in spinal surgery has been considered sensitive to predict postoperative neurological recovery. In this series, transcranial stimulation consisted of trains of five pulses at a constant voltage (200–600 V). For the normalization of MEP, we recorded compound muscle action potentials (CMAP) after peripheral nerve stimulation, usually on the median nerve at the wrist 2 seconds before or after each transcranial stimulation of the motor area, for all operations. The sensitivity and specificity of MEP monitoring was 100% and 97.4%, respectively, or 96.9% with or without CMAP compensation (if the threshold of postoperative motor palsy was defined as 20% relative amplitude rate [RAR]). The mean RAR after CMAP normalization, of the most affected muscle in the patient group with excellent postoperative results (recovery rate of a Japan Orthopedic Association score of more than 50%) was significantly higher than that in the other groups ($p = 0.0224$). All patients with an amplitude increase rate (AIR) with CMAP normalization of more than 20% achieved neurological recovery postoperatively. Our results suggest that if the RAR is more than 20%, postoperative motor palsy can be avoided in spinal surgery. If the AIR with normalization by CMAP after peripheral nerve stimulation is more than 20%, neurological recovery can be expected in spinal surgery.

1. Introduction

Since most spinal surgeries are functional surgeries, neurological worsening after a spinal operation is never acceptable. To prevent such postoperative neurological worsening, intraoperative neurophysiological monitoring is widely applied in spinal surgery [1–5]. Motor symptoms are most important in operations for the treatment of compressive spinal and spinal nerve diseases, and the motor-evoked potential (MEP) is an important target for neurophysiological monitoring in spinal surgery [6,7]. MEP has become popular due to recent rapid advances with propofol anesthesia and the train stimulation method [1,8]. To record MEP, we must stimulate the primary motor cortex in the frontal lobe or pyramidal tract by one of two methods. The first involves direct stimulation of the motor cortex at 10–20 milliamps using subdural electrodes over the primary motor area by phase reversal of the somatosensory evoked potential (SEP; cortical MEP) [7,9–13]. The other method involves high voltage (several hundred volts) transcranial stimulation using screw electrodes that have been placed in the scalp [11,14–16]. Transcranial stimulation of the motor area with recording of the peripheral electromyogram (EMG) is the most popular method of MEP monitoring during spinal surgery and it has also been shown to be very sensitive [17–19].

Intraoperative MEP monitoring has been performed solely for the prevention of newly developed postoperative motor palsy. Interestingly, recovery from mild motor symptoms such as a decrease in grasp force, impairment of fine motor skills and intermittent claudication, which are commonly seen in patients

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undergoing spinal surgery, may be predicted by MEP monitoring [5]. In this study, we examined not only the threshold relative amplitude for postoperative motor palsy but also the usefulness of intraoperative monitoring by MEP to predict postoperative neurological recovery in compressive spinal and spinal nerve diseases.

2. Materials and methods

2.1. Patient population

Intraoperative MEP monitoring was performed in 196 consecutive spinal surgeries for the treatment of compressive spinal and spinal nerve diseases from April 2006 to February 2015. The surgeries consisted of 79 cervical spinal operations including 42 cervical laminoplasties (29 at C3–6) and 37 cervical anterior fusions (16 for two levels and 32 included C5/6), 117 lumbar spinal operations including 41 lumbar laminectomies (12 were at L4/5, 10 were at L3–5), 43 lumbar fenestrations (24 were for two levels and 32 included L4/5), 27 lumbar discectomies (12 were at L4/5 and 13 were at L5/S1) and five posterior lumbar-thoracic interbody fusions. All of the patients had motor symptoms to some extent and we did not operate on patients with only sensory symptoms, except for pain. Most of the patients had a history of neurological worsening 3 months before surgery. We obtained written informed consent from all of the patients, including permission for MEP monitoring.

2.2. MEP monitoring

With regard to anesthesia, total intravenous anesthesia with propofol (usually at a constant dose of about 0.06 mg/kg/hour) was used in all operations [8]. As a muscle relaxant, vecuronium bromide at 0.1 mg/kg was usually used only for tracheal intubation. A set of screw electrodes (Unique Medical, Tokyo, Japan) with the cathode on the more affected side and the anode on the contralateral side were placed 2 cm anterior to C3 or C4 by the international 10–20 electroencephalogram system. The screw electrodes were inserted into the scalp and contacted the skull surface. They are stronger than conventional needle electrodes and resistant to high voltage electric stimulation. Stimulation consisted of trains of five pulses at a constant voltage by a Multi-Path D185 (Digitimer, Hertfordshire, UK) or Electric Stimulator SEN-4100 (Nihon Kohden, Tokyo, Japan). Stimulation at 200–400 V was most common in our series, except for patients in whom recording was difficult. The duration of each pulse was 0.2 milliseconds and the inter-pulse interval was 2 milliseconds. Surface electrodes for recording EMG responses were placed on the abductor pollicis brevis and abductor hallucis muscles as well as on other affected muscles. EMG were recorded with Neuropack-2, MEB-2208, MEB-9204, MEB-2306, or MEE-1208 (Nihon Kohden). The amplitude of each MEP was measured from the baseline to the first negative peak of the waves.

Surface electrodes for applying stimulation for the normalization of MEP by compound muscle action potential (CMAP) after peripheral nerve stimulation were usually placed on the median nerve at the wrist. CMAP by single, bipolar supramaximum stimulation (20–50 milliamps), which had been determined at the beginning of the operation, usually on the median nerve at the wrist 2 seconds before or after each transcranial stimulation of the motor area, was recorded in all operations as previously described [19,20]. The amplitudes of MEP and CMAP after peripheral nerve stimulation were measured. The relative amplitude rate (RAR) and RAR normalized by the amplitude of CMAP were calculated automatically with Microsoft Excel (Microsoft, Redmond, WA, USA).

2.3. Outcome assessment

Postoperative motor palsy was defined as less than 2/5 in the Medical Research Council (MRC) manual muscle test grading system 1 week after the operation. Preoperative and 1 week, 1 month, 3 month, 6 month, and 1 year postoperative Japan Orthopedic Association (JOA) scores were assessed by a third party, and the recovery rate was defined as described by Hirabayashi [21]. Using the best JOA score postoperatively, all patients were divided into four groups according to recovery rate: excellent (E; JOA recovery rate $\geqslant$ 50%), good (G; recovery rate 0 < JOA score < 50%), no change (N; JOA recovery rate = 0%), and worsened (W; JOA recovery rate < 0%). In each group, the mean RAR, with or without normalization by CMAP after peripheral nerve stimulation, was calculated and the RAR for functional recovery from compressive spinal and spinal nerve diseases was estimated from these results. The numbers in groups E and G compared to groups N and W, above and below the amplitude increasing rate (AIR) of the most affected muscle, were compared at every 10% increment within the range of 0–100% for convenience, with or without CMAP normalization in cervical operations.

3. Results

MEP could be recorded in all 196 consecutive spinal operations. Overall, no adverse events were noted with high voltage transcranial stimulations or EMG recordings. In all patients, sufficient postoperative decompression was proved by postoperative imaging.

3.1. Sensitivity and specificity of MEP monitoring

For each spinal operation, sensitivities and specificities were calculated according to the RAR (70–0%, every 10% interval) with or without normalization by CMAP after peripheral nerve stimulation. Receiver operating characteristic (ROC) analyses were employed to calculate the threshold for postoperative motor palsy (less than MRC grade 2/5), as shown in Figure 1 [22]. The threshold of postoperative motor palsy was 20% of RAR, and was also calculated by ROC analysis. In 196 spinal operations, the RAR of 10 patients without CMAP normalization and nine patients with CMAP normalization at the end of the operation was less than 20%. Among these patients, four who received cervical operations experienced new postoperative motor palsy of less than MRC grade 2/5. The other six and five patients, respectively, were considered false positives. If a 20% RAR of MEP was defined as the threshold for postoperative motor palsy, the specificity of MEP monitoring in our cervical operations was $(196 - 6)/196 \times 100 = 96.9\%$ without CMAP normalization, and $(196 - 5)/196 = 97.4\%$ with CMAP normalization. None of the patients except the four mentioned above had new postoperative motor palsy. None of the patients were false negatives; none had postoperative motor palsy without a less than 20% decrease in RAR. Therefore, the sensitivity of MEP monitoring in cervical operations in our consecutive series was 100% at 20% RAR, with or without CMAP normalization.

3.2. Monitoring results and neurological recovery

Among all the 196 patients who underwent surgery for compressive spinal and spinal nerve diseases, 110 were in group E, 75 were in group G, eight were in group N, and three were in group W. Box plots of the RAR in the four groups are shown in Figure 2.