Electromyographic response of facial nerve stimulation under different levels of neuromuscular blockade during middle-ear surgery

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Abstract

Objective: To investigate facial nerve monitoring in patients receiving the partial nondepolarizing neuromuscular blocking agents (NMBAs), remifentanil and propofol.

Methods: Patients with normal facial function and advanced middle-ear disease were enrolled. For total intravenous anaesthesia (TIVA), propofol and remifentanil were infused as induction/maintenance anaesthesia. Stimulation thresholds and amplitudes were recorded at each train-of-four (TOF) nerve stimulation level. Time differences between start of TOF and electromyographic (EMG) amplitude decreases (Ti), and between complete recovery of TOF and EMG amplitudes (Tr), were calculated.

Results: Fifteen patients were enrolled. Mean ± SD Ti was 3.4 ± 1.28 min; Tr was 18.7 ± 4.41 min. Amplitude of stimulation was apparent mostly at TOF level 1. In most cases, no or a weak response (<100 mV) was observed at TOF 0. Mean ± SD threshold of electrical stimulation was 0.31 ± 0.10 mA at TOF 1. At TOF > 2, all cases showed EMG response on electrical stimulation.

Conclusions: Induction of TIVA using propofol and remifentanil provided reliable conditions for delicate microsurgery. Minimal N MBA use, considered as producing TOF levels > 1, was sufficient for facial nerve monitoring in neuro-otological surgery.

Keywords
Facial nerve, monitoring, electromyography, total intravenous anaesthesia, propofol, remifentanil train-of-four, neuro-otological surgery

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Introduction

Given the unique location, size and delicate content of the middle ear, great care must be taken during the perioperative period in patients undergoing middle-ear surgery. Special considerations include the provision of a bloodless surgical field, attention to the patient’s head position, airway management, facial nerve monitoring, recognition of the effect of nitrous oxide on the middle ear, and the prevention of postoperative nausea and vomiting.1–4 Neuromuscular blocking agents (NMBAs) commonly used in anaesthesiology for muscle relaxation frequently impede intraoperative electromyographic (EMG) monitoring of the motor-evoked potentials of the facial nerve.5 NMBAs act directly on the neuromuscular junction and block signal transmission, which provides favourable surgical conditions but may interfere with facial nerve monitoring.6

Delicate microsurgical intervention demands absolute immobility of the patient in neurosurgery, and facial nerve injury is a devastating potential complication.7 Intraoperative monitoring of the facial nerve during neurosurgical procedures is widely accepted, to aid in the preservation of facial nerve function.8–11

The preservation of facial nerve function can be achieved by using large doses of narcotics and volatile anaesthetic agents, without the administration of a muscle relaxant.8,11–13 This anaesthetic technique is poorly tolerated by some patients with severe haemodynamic instability, however, necessitating the use of vasopressors to support the circulatory system.6 Others have recommended the use of partial NMBAs, which protect patients from the cardiovascular depression that results from high-dose anaesthesia while keeping patients immobilized.14,15 Surgeons using this technique should be aware that sudden (unexpected) patient movement may jeopardize surgical success. Maintaining a balance between haemodynamic stability and absolute immobility, while preserving an optimal condition for facial EMG monitoring, is essential.

Propofol, which is a widely used intravenous (i.v.) anaesthetic agent, does not enhance the neuromuscular blockade produced by NMBAs. Propofol causes the widespread inhibition of the N-methyl-D-aspartate (NMDA) subtype of the glutamate receptor through the modulation of sodium-channel gating, and contributes to the central nervous system (CNS) effects of the drug, with no effect on evoked EMG or twitch tension.16,17 Although many different compounds can be used in various combinations to provide total i.v. anaesthesia (TIVA), the combination of remifentanil and propofol produces excellent results. Remifentanil provides analgesia and haemodynamic stability while blunting responses to noxious stimuli; propofol provides hypnosis and amnesia, and is an antiemetic.18,19 Thus, remifentanil and propofol TIVA can be used as an optimal anaesthetic technique, especially for neuromuscular monitoring of the peripheral nervous system, because blockade levels can be controlled simply by administering the appropriate dosage of a nondepolarizing NMBA; the appropriate dosage can be determined readily from response to train-of-four (TOF) nerve stimulation.20,21

In TOF nerve stimulation, four supra-maximal stimuli (2 Hz) are given every 0.5 s and each stimulus in the train causes the muscle to contract; the degree to which the response diminishes provides the basis for evaluation. The degree of blockade by nondepolarizing NMBAs can be determined directly from the TOF response.22,23 The present study investigated the effectiveness of facial nerve monitoring in patients who had received partial nondepolarizing NMBAs and a combination of remifentanil and propofol to induce TIVA.
The appropriate level of NMBAs for facial nerve monitoring in neurosurgery was also determined.

**Patients and methods**

**Study population**

Consecutive patients with normal facial function who had advanced middle-ear disease (characterized by a dehiscent fallopian canal on the tympanic segment or a defective fallopian canal due to advanced cholesteatoma) were enrolled in this prospective study. The study was conducted at Inje University, Ilsan Paik Hospital, Gyeonggi-do, Republic of Korea, between October 2011 and September 2012.

Prior to surgery, all patients were checked by temporal bone computed tomography scan, to investigate the fallopian canal and integrity of the intratemporal facial nerve, in addition to middle-ear disease. Patients were scheduled for elective otological surgery (intact canal wall or open mastoidectomy with tympanoplasty) under general anesthesia with TIVA. Those who had an intact fallopian canal, without facial nerve exposure or interference of facial nerve integrity, were excluded from the study. There were no other specific inclusion or exclusion criteria for the study.

The study was approved by the Committee for Medical Ethics of Inje University Hospital. Written informed consent was obtained from all patients prior to enrolment.

**General anaesthesia protocol**

All patients received premedication of 0.05 mg/kg midazolam and 0.2 mg glycopyrrolate intramuscularly (i.m.) at 1 h and just before the induction of anaesthesia, respectively. Standard evaluations using electrocardiography, pulse oximetry and noninvasive blood pressure monitoring were carried out. For TIVA, propofol and remifentanil were administered concurrently by i.v. infusion using a target-controlled infusion system (Orchestra® Base Primea, Fresenius Vial S.A.S., Brezins, France), for induction and maintenance of anaesthesia. Effect-site concentrations of propofol and remifentanil were kept within the ranges of 2–5 μg/ml and 2–5 ng/ml, respectively. After loss of consciousness and TOF calibration, 0.6 mg/kg rocuronium bromide i.v. was administered as a muscle relaxant. Depth of anaesthesia was monitored using a bispectral index score monitor (A-200; Aspect Medical Systems, Newton, MA, USA) and maintained within the range of 40–60. Controlled ventilation was performed with 40% oxygen in air to maintain end-tidal CO₂ at 35–40 mm Hg during surgery. Body temperature was maintained at 36–37°C using a forced-air warming system throughout surgery.

**Facial monitoring**

Intraoperative four-channel facial nerve EMG monitoring was performed with a NIM-Response 3.0 system (Medtronic Xomed, Jacksonville, FL, USA) in all patients. Two bipolar-paired subdermal needle electrodes were placed in the orbicularis oris and orbicularis oculi. The difference between electrode impedances remained <1 kΩ during the recordings for all channels. The facial nerve was electrically stimulated by a monopolar probe with a 0.5-mm tip. Square current waves of 100-ms duration at a frequency of 4 Hz were applied as stimulation.

Two parameters were measured: (1) maximal amplitude of the responses (in μV) on one of the two channels after supramaximal stimulation at 2 mA (indicative of intensity); (2) stimulation threshold (in mA), determined by increasing the stimulation intensity in increments of 0.05 mA between 0.1 and 0.6 mA until a response >100 μV on at least one channel was obtained.
TOF nerve stimulation

Train-of-four (TOF) nerve stimulation was used to evaluate the degree of neuromuscular function. TOF nerve stimulation was defined by four supramaximal stimuli (2 Hz) given every 0.5 s, causing the muscle to contract. The degree to which the response diminished provides the basis for evaluation.

After induction of general anaesthesia, neuromuscular function was monitored at the adductor pollicis of the thumb, using the TOF-Watch (Organon Ireland, Dublin, Republic of Ireland). The device was stabilized by using 1-min repetitive TOF stimulation, followed by 50-Hz tetanic stimulation for 5 s and 3–4 min of repetitive TOF stimulation. The supramaximal threshold was determined using the CAL 2 mode and the acceleration transducer was calibrated in the standard fashion, described in the manufacturer's instruction booklet.

After calibration of the TOF-Watch, each participant received 0.6 mg/kg rocuronium bromide i.v. and the trachea was intubated when the level was 0, after full recovery of TOF level at facial nerve exposure. Additional bolus doses of 0.15 mg/kg rocuronium bromide i.v. were administered until the TOF level decreased to 0. As the effects of NMBAs disappeared, the TOF level and EMG amplitude were concurrently recorded. All neuromuscular response data were recorded on an interfaced laptop.

Study procedure

After complete recovery of peripheral neuromuscular function following NMBA administration during induction, the baseline facial nerve response evoked by electrical stimulation was recorded. Then, repeated doses of rocuronium bromide were given to attain TOF level 0, and administration of rocuronium bromide ceased until the targeted TOF level at 0, 1, 2, 3 and 4 s was reached. Stimulation thresholds and amplitudes of facial EMG responses were recorded at each TOF level. Preliminary experiments revealed a difference in response timing between the adductor pollicis and facial muscles. At the first additional injection of rocuronium bromide, the time difference between the start of TOF decrease and that of the EMG amplitude decrease was calculated (Ti). After recovery from NMBAs, the time difference between complete recovery of TOF and that of EMG amplitude was calculated (Tr).

Statistical analyses

Statistical analyses were performed using the SPSS® software package, version 16.0 (SPSS Inc., Chicago, IL, USA) for Windows®. Differences between groups were tested for statistical significance using an independent -samples t-test and Fisher’s exact test. A P-value of <0.05 was considered to be statistically significant.

Results

Fifteen patients – eight women and seven men, mean age 59.1 years (range, 34–80 years) – were enrolled in the study. Thirteen patients underwent primary surgery and two patients underwent surgical revision. None of the patients had temporary or permanent facial nerve paralysis before or after surgery. In all cases, the facial nerve could be identified and clearly visualized during surgery, and the baseline amplitude was obtained after the TOF level of 4.

The mean ± SD Ti was 3.4 ± 1.3 min and the mean ± SD Tr was 18.7 ± 4.4 min (Figure 1). The amplitude of stimulation on the exposed segment of the facial nerve was apparent mostly at a TOF level of 1. In most cases, no response or a weak (<100 μV) response was observed at a TOF level of 0 (Figure 2A). The mean ± SD threshold of electrical stimulation was 0.31 ± 0.10 mA at a TOF level of 1. At TOF levels >2, all cases
showed an EMG response on electrical stimulation (average threshold, 0.26 ± 0.10 mA). No significant difference in thresholds was observed between TOF levels of 2 and 3, or between levels of 3 and 4. The facial nerve stimulation threshold was significantly higher at TOF level 1 than at TOF level 2 (P < 0.05). The mean ± amplitudes of EMG response were 149.1 ± 75.6 μV at TOF level 1, 307.2 ± 149.5 μV at level 2, 403.8 ± 134.3 μV at level 3 and 449.6 ± 110.7 μV at level 4 (Figure 2B).

Discussion

The NMBAs can render the facial musculature unresponsive to electrical and mechanical stimulation in neurosurgery. For this reason, anaesthetists are asked to avoid the use of NMBAs when maintaining anaesthesia during surgery.6 Although the best means of protecting the facial nerve in otological surgery is to possess a complete knowledge of its anatomy, the goals of intraoperative facial nerve monitoring include early identification of the facial nerve by electrical stimulation, warning the surgeon of any unexpected facial nerve manipulation and reducing mechanical trauma to the facial nerve during the operation.24

Unresponsiveness to intraoperative electrical stimulation can be an issue for surgeons undertaking delicate microsurgical interventions because no response at a high current suggests substantial facial nerve damage. Thus, maintaining a balance between haemodynamic stability and absolute immobility, while preserving optimal conditions for facial EMG monitoring, is essential. The present study investigated the effectiveness of facial nerve monitoring in patients who had received partial nondepolarizing NMBAs and a combination of remifentanil and propofol to induce TIVA. In addition, the appropriate levels of
Figure 2. Train-of-four (TOF) and electromyographic (EMG) responses in patients receiving partial nondepolarizing neuromuscular blocking agents (NMBAs), and remifentanil plus propofol, to induce total intravenous anaesthesia (TIVA). (A) Amplitude levels of stimulation on the exposed segment of the facial nerve were apparent mostly at TOF level 1; in most cases, no response or a weak (< 100 μV) response was observed at TOF 0; mean ± SD threshold of electrical stimulation was 0.31 ± 0.10 mA at TOF 1; at TOF > 2, all cases showed an EMG response to electrical stimulation (mean ± SD threshold, 0.26 ± 0.10 mA).

(B) Mean ± SD amplitudes of EMG response were 149.1 ± 75.6 μV at TOF 1, 307.2 ± 149.5 μV at TOF 2, 403.8 ± 134.3 μV at TOF 3, and 449.6 ± 110.7 μV at TOF 4. Each dot represents data from each patient.
NMBAs for facial nerve monitoring in neurosurgery were determined. The facial nerve was sequentially stimulated at various TOF levels to determine an adequate and suitable anaesthetic technique for facial nerve monitoring. In all cases, NMBAs did not affect the facial musculature when the surgeon reached the facial nerve. The stimulation threshold of the facial nerve at TOF level 1 differed significantly from that at other TOF levels. Above TOF level 2, NMBAs administration with TIVA provided sufficient immobility, while preserving the optimal conditions for facial EMG monitoring.

Some authors have reported a difference in sensitivity between facial and ulnar nerve responses to NMBAs. The present study showed the facial musculature to be less sensitive than the hypothenar muscle to the neuromuscular effect of NMBAs. This allowed the evaluation of the time difference in NMBAs effectiveness, between the responses of facial and ulnar nerves.

In this anaesthetic technique using NMBAs and TIVA, the mean TOF levels showed no increased risk of iatrogenic facial nerve injury. Except for a short period at level 0, which lasted for 10–15 min after additional NMBAs injection for maintenance, the facial nerve was not endangered by NMBAs during surgery. Propofol is widely used as an i.v. agent for the induction of general anaesthesia in patients >3 years of age. Its use is characterized by rapid onset and short duration of action which, together with its stress control and amnesic properties, make it an ideal hypnotic agent for use during surgical procedures. In contrast to inhalational anaesthetics, which potentiate the neuromuscular blocking effects of NMBAs, propofol mainly contributes to the CNS effects of the drug on spinal cord neurons; it does not enhance neuromuscular blockade induced by NMDAs that have no effect on the evoked EMG. We consider propofol to be a good anaesthetic because it provides good surgical conditions for facial nerve monitoring and favourable postoperative conditions for middle-ear surgery, due to its antiemetic effects. In addition, propofol produces a favourable sense of wellbeing in the patient. Remifentanil is a synthetic opioid, with potent and selective \( \mu \)-opioid receptor agonist activity, that is rapidly metabolized in the blood and tissue, with an elimination half-life of ~9 min. Remifentanil was used in the present study as it has been used successfully in without muscle relaxants anaesthesia, and maintains a stable haemodynamic state during surgery. In TIVA, using propofol and remifentanil, the level of neuromuscular blockade can be controlled simply with NMBAs. Adjustment of NMBAs should, however, be made by administering larger maintenance doses at more frequent intervals, or by using higher infusion rates for otological surgery.

Intraoperative anaesthetic management of patients undergoing neurotological surgery is made more difficult by the need to maintain a balance between haemodynamic stability and absolute immobility, while providing optimal conditions for facial EMG monitoring. With TIVA using propofol and remifentanil, the controlled infusion of NMBAs titrated to TOF level 1 and EMG responses in the hypothenar muscle did not impair the capacity of facial nerve monitoring to detect facial nerve injury. Given the variability in NMBAs effects on different muscles, the time difference between TOF levels of the ulnar and facial nerves should be considered when assessing facial EMG. The present study suggests that the induction of TIVA using propofol and remifentanil provides reliable surgical conditions for delicate microsurgery, and that minimal NMBAs use – which is considered to be that which produces TOF levels >1 in the adductor pollicis – is sufficient for facial nerve monitoring in neurotological surgery.
Declaration of conflicting interest

The authors declare that there are no conflicts of interest.

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References


