12 Intraoperative Monitoring

Shi-Ting Li and Ting-Ting Ying

Abstract

This chapter provides an overview of the tests that constitute the tools in intraoperative neurophysiology of cranial nerves. The general introduction and equipment of monitoring are described. This chapter gives a practical presentation of each neurophysiological method regarding the following: (1) the principle on which it is based, (2) the methodology for stimulation and recording, (3) the intraoperative interpretation, and (4) the various types of anesthetics and their effects on neurophysiological monitoring. At the end of the chapter, a detailed example of the combined use of intraoperative monitoring for MVD surgery is discussed.

Keywords

Intraoperative monitoring • Cranial nerve • Evoked potentials • Electromyography • ZLR • F wave • Blink reflexes • Anesthetics

12.1 Introduction

With the rapid developments in neuroscience, intraoperative neurophysiological monitoring (IOM or IONM), as a new and exciting field, has grown rapidly over the past two decades. IOM is gradually becoming part of standard medical practice, for it can provide information regarding the functional integrity of the nervous system of a patient who is anesthetized and therefore cannot be neurologically examined. Common IOM techniques include electroencephalography (EEG), electromyography (EMG), evoked potentials (EPs), and nerve conduction velocity (NCV).

Cranial nerves are at risk of being injured during various kinds of neurosurgical operations. By offering early detection of reversible neurophysiological dysfunction during surgery, neuro-monitoring can provide prognostic information about clinical outcomes and prevent the occurrence of permanent neurological damage. Neurophysiological methods are increasingly used for diagnostic support in operations such as those involving peripheral nerves. In certain operations, intraoperative neurophysiology can

S.-T. Li (✉) • T.-T. Ying
Department of Neurosurgery, XinHua Hospital, Shanghai Jiao Tong University School of Medicine. The Cranial Nerve Disease Center of Shanghai Jiao Tong University, Shanghai, China
e-mail: lsting66@163.com

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increase the likelihood of achieving the therapeutic goal of an operation. Intraoperative neurophysiological recordings have shown to be of help in identifying the offending blood vessel in a cranial nerve disorder (hemifacial spasm, HFS) (Moller and Jannetta 1986).

12.2 Equipment and Electrodes

The choice of equipment for intraoperative monitoring is very important. The equipment should have several desirable features which, although not absolutely necessary for routine clinical recordings, are of special importance for intraoperative recordings. For instance, it should allow for simultaneous multimodality recordings, such as EMG and evoked responses, to meet the needs of specific operations. A typical system includes one or more programmable devices that can deliver auditory, visual, and electrical stimuli of variable amplitude, duration, and rate; various types of electrodes for delivering electrical stimuli and for recording electrophysiological activity from the scalp, nerves, and muscles; a head box for selecting among different electrode groups to be connected to the amplifiers; a set of amplifiers; a display monitor; a printer; and often a modem or network connection for remote monitoring (Zouridakis and Papanicolaou 2000). All parts are connected to a computer which, depending on the kind of recordings, controls stimulus delivery, data collection, filtering, averaging, display, printing, as well as remote transmission and permanent storage of the data (Zouridakis and Papanicolaou 2000). However, it should allow modifications in the recording protocol and display parameters, if necessary, thus permitting fast interpretation of the results.

There are several types of stimulation electrodes for both stimulation and recording, including stick-on electrodes, metal cup electrode, subdermal needles, corkscrew electrode, and metal probes, which can be monopolar or bipolar. The efficiency of stimulus delivery or recording is determined by selection of the appropriate electrode type and its correct placement.

The subdermal needles are more practical in the operating room as they can be applied quickly after the patient has been anesthetized without the need for skin preparation. They are usually easy to secure and provide stable and steady low electrode-skin impedances. If possible, the addition of more "redundant" electrodes at both recording and ground sites can be useful in case electrodes get dislodged during surgery.

12.3 The Effects of Anesthetics on Intraoperative Neurophysiology Studies

Various types of anesthetics were found to affect neurophysiology studies used in intraoperative monitoring because of the effects they have on cerebral blood flow, perfusion, and metabolic rate. General anesthesia consists of several components, including analgesia (suppression of response to pain), sedation (induction of sleep), amnesia (suppression of recollection of the intraoperative experience), and muscle relaxation (suppression of muscle contraction). It may also include hypotension (decreased blood pressure) and hypothermia (decreased body temperature) which might also affect the neurophysiological signals (Zouridakis and Papanicolaou 2000). Thus, interpretation of all neurophysiological recordings should always take into account the effects of changes in anesthesia regime which are very similar to the changes from surgical intervention. Pulse oximetry, ECG, arterial blood pressure, capnography, body temperature, and muscle twitch response should be routinely monitored and recorded during the surgeries. Communication with the anesthesiologist is very critical. Successful neurophysiological intraoperative monitoring requires a team approach between the anesthesiology, surgical, and NIOM teams (Galloway et al. 2010). A detailed discussion of the various types of anesthetics and their effects on neurophysiological monitoring will be described at the end of each method of monitoring.

12.4 Monitoring Techniques and Exclusionary Criteria

12.4.1 Brain Stem Auditory Evoked Potentials

Hearing loss (HL) is one of the most common complications after microvascular decompression (MVD) (Møller and Møller 1989; Samii et al. 2002).

Brain stem auditory evoked potentials (BAEPs) monitoring, also named auditory brain stem responses (ABRs), has been widely used as a classical and noninvasive technique to reduce the risk of hearing impairment with surgery in the region of the cerebellopontine angle (CPA), including MVD (López 2004). The normal BAEPs consist of 5–7 vertex-negative peaks that occur between 2 and 10 ms after the presentation of a high-intensity transient sound such as a click or a short, high-intensity tone burst (Fig. 12.1). Specific anatomic locations have been proposed as the predominant source for the generation of each of these waveforms: wave I, distal auditory nerve; wave II, cochlear nucleus and proximal auditory nerve; wave III, superior olivary nucleus (lower pons); wave IV, lateral lemniscus; wave V, inferior colliculus; wave VI, medial geniculate body; and wave VII, auditory radiations. In addition to reflecting the conduction in the auditory pathways, BAEPs also provide valuable information about the general function of the brain stem.

The cochlear nerve may be damaged for the following reasons during the surgery: (1) stretching of the cochlear nerve while retracting the cerebellum, (2) manipulation of the labyrinthine artery and/or the anteroinferior cerebellar artery, (3) direct trauma by instruments or a nearby coagulation, and (4) new compression of the cochlear nerve at end of surgery by the interposed Teflon between the compressive vessel and the VIIth-cochlear nerve complex (Polo et al. 2004; Sindou 2005). During BAEP monitoring, careful assessment of the changes in the pattern of BAEPs and analysis of their relationship to the surgical maneuvers applied should determine whether the changes reflect damage to or potentially reversible dysfunction of the auditory pathways in the ear, auditory nerve, or brain stem. Thus, this test can be used in surgical procedures

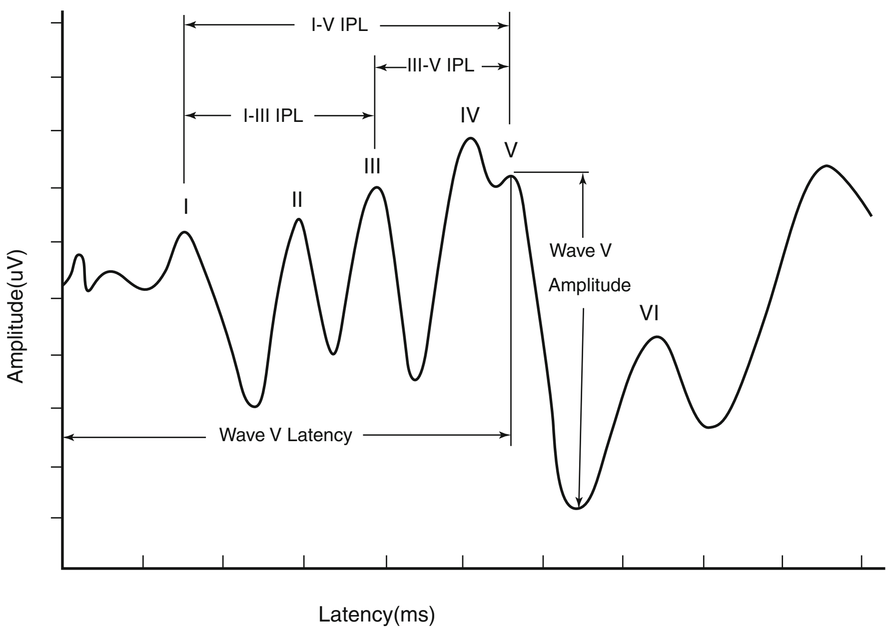

Fig 12.1 Typical recording of brain stem auditory evoked potentials

such as microvascular decompression of the facial nerve or trigeminal nerve or tumor removal at CPA.

12.4.1.1 Stimulation and Recording

Stimulation Sound stimulus is delivered through miniature electromagnetic earphones inserted in the ear canals and secured though sponge (molded foam) ear inserts connected to a transducer by plastic tubing. Dislodgment or kinking of this tubing can lead to complete absence of all BAEP components or reduction in amplitudes and delay in latencies.

Sound Intensity Clicks of alternating polarity are commonly used for intraoperative monitoring to cancel the stimulus artifact. Usually, the stimulus intensity needed is at or above 70 dB nHL, but higher intensities are often needed if there is a preexisting hearing loss.

Stimulus Rate To eliminate contamination with electrical artifacts, exactly 10 Hz or multiples of the used power frequency should be avoided. Usually, a rate between 20 and 40 Hz (e.g., 33.1 Hz) is used, and the selected rate should be used consistently for the rest of the surgery. In order to eliminate the electrical noises in the operating room, several hundreds of averaged trials are often necessary to obtain reliable signals.

Recording Electrodes and Band Pass Electrode placement follows the EEG 10–20 international system. The standard setup of recording electrodes should positioned as follows: Channel (1) vertex to ipsilateral earlobe/mastoid (Cz-Ai/Mi) and Channel (2) vertex to contralateral earlobe/mastoid (Cz-Ac/Mc). Two additional channels could also be used: Channel (3) ipsilateral earlobe/mastoid to contralateral earlobe/mastoid (Ai-Ac or Mi-Mc) and Channel (4) vertex to noncephalic reference (Cz-Nc), e.g., vertex to cervical (Cz-Cv2). Typical filter settings are a low-frequency filter of 100 Hz and a high-frequency filter of 3 kHz. As BAEPs are of very short latencies and small amplitudes, time base of 1 ms (sweep of 10 ms) and sensitivity of 0.1–0.2 uV/division are used.

12.4.1.2 Intraoperative Interpretation

A set of baselines should be obtained after anesthesia induction and patient positioning. Baseline responses should contain clear and reliable components and also be compared with throughout the surgery using the same acquisition and stimulus parameters.

As with the 2006 criteria published by the American Clinical Neurophysiology Society for recording standard BAEPs, analysis typically involves monitoring for the presence of waves I, III, and V. The measurements must include the following: (1) wave I peak latency, (2) wave III peak latency, (3) wave V peak latency, (4) I–III interpeak interval, (5) III–V interpeak interval, (6) I–V interpeak interval, (7) wave I amplitude, (8) wave V amplitude, and (9) wave IV–V/I amplitude ratio (Society 2006).

Traditionally, the most important criterion involves the latency and the amplitude of peak V. Some authors have suggested that a latency prolongation of as little as 0.5 ms of the wave V is significant (Acevedo et al. 1997). It has been found that a reduction of amplitude more than 50 % in wave V was a stronger indicator of hearing than latency (Hatayama and Mollar 1998; Legatt 2002; Jo et al. 2011). However, Polo et al. (2004) reported that the I–V interpeak latency, or the latency of wave V, was an effective and predictive indicator of postoperative hearing, whereas others have suggested that hearing loss occurs when wave V is completely lost (Schlake et al. 2001; Lee et al. 2009). It has been also proposed that patients with HL had higher rates of loss in the amplitude of wave V and prolongation in the interpeak latency of peaks I–V during MVD (Ying et al. 2014). The criteria for significant intraoperative BAEP change are still not universally accepted. It has been suggested that no single value can be used to either predict when hearing will be preserved or lost, and a sliding scale approach should be used (Polo et al. 2004).

12.4.1.3 Anesthesia Requirements

The effects of various drugs most commonly used in anesthesia on the BAEPs are summarized and listed in Table 12.1.

Table 12.1 Effects of anesthetic agents on BAEP amplitude and latency

Agent	Amplitude	Latency
Nitrous oxide (N_2O)	↓	–
Inhalational anesthetics	–	↑
Propofol	–	↑
Barbiturates	–	↑
Ketamine	–	↑
Opiates	–	–
Benzodiazepines	–	–
Muscle relaxants	–	–

Hypothermia increases the latency and decreases the BAEP amplitude, whereas hyperthermia decreases the amplitude and the latency of the responses (Markand et al. 1987)

12.4.2 Brain Stem Trigeminal Evoked Potentials

The trigeminal somatosensory system, which provides sensation to the face and the anterior two-thirds of the tongue, can be monitored using standard SSEPs. It has been shown that monitoring of SSEP is useful in intraoperative monitoring of the medulla oblongata and in trigeminal rhizotomy in patients with trigeminal neuralgia in whom it may be of value to monitor neural conduction in the trigeminal nerve (Stechison and Kralick 1993). Recordings from electrodes on the scalp can be used for monitoring the ascending trigeminal sensory pathways when elicited by electrical stimulation of the peripheral trigeminal nerve.

12.4.2.1 Stimulation and Recording

Stimulation Sites Stimulation of the trigeminal nerve is performed with needle electrodes introduced subcutaneously into the upper (anode) and lower (cathode) lips (Malcharek et al. 2011).

Stimulation Intensity and Rate Each set of the BTEP was stimulated with 300 trials to confirm the repeatability of the obtained cortical response. The frequency of the stimulation was 4.7 Hz, and the duration of each stimulus was 0.2 ms. The polarity of the stimulation was alternating to avoid large baseline shifts. The intensity of stimulation during each set of trials varied from 7 to 16 mA (Malcharek et al. 2011).

Fig 12.2 Characteristic wave of trigeminal SSEP under general anesthesia

Recording Electrodes and Band Pass The cortical response is recorded from electrodes situated at the scalp. Recordings were performed with needle electrodes placed at C5 or C6 (the contralateral side of the scalp) with Fpz as reference, according to the International 10/20 system (Malcharek et al. 2011). The waveform pattern was maintained irrespective of whether the reference site was Fpz or Cv7 (Fagade and Wastell 1990). Signals are filtered with band-pass filter from 0.1 to 1000 Hz. Sampling rate is 5000 Hz.

12.4.2.2 Intraoperative Interpretation

Short-latency, negative components elicited by electrical stimulation of branches of the trigeminal nerve have latencies of 0.9, 1.6, and 2.6 ms when recorded from the trigeminal nerve where it enters the brain stem (Stechison and Kralick 1993). These potentials represent neural activity in the trigeminal nerve, not in any other rostral structures, and such recordings can, thus, only be used to monitor the trigeminal (sensory) nerve (Oikawa et al. 2000). Long-latency components are also followed. Latencies and amplitudes of the N13 and P19 peaks were measured (Malcharek et al. 2011) (Fig. 12.2).

Different trigeminal evoked potentials showed significantly increased latencies and statistically significant threshold elevations on the affected sides (Bennett and Jannetta 1983); tSSEP could represent a fast and safe way of determining trigeminal afferent function in a laboratory setting (Adamec et al. 2014).

A significant difference in BTEP latencies was found between the normal side and the affected side before the surgery. While in the patients who were released from pain after the MVD, the BTEP latencies of the two sides did not differ significantly (Vriens and Pasman 1994). The latencies after MVD became shorter than before the surgery, and the intensity of stimulation necessary to reach the threshold was lower after the surgery (Adamec et al. 2014).

12.4.3 Somatosensory Evoked Potentials of Upper Extremity

Somatosensory evoked potentials (SSEPs) can be elicited by electrical stimulation of a peripheral nerve, such as the median/ulnar nerve at the wrist or the posterior tibial nerve at the ankle. It is used intraoperatively to monitor blood perfusion of the cortex or the spinal cord and the structural and functional integrity of peripheral nerves and spinal nerve roots.

Injury of the brachial plexus secondary to malposition of the patient during surgery is a significant perioperative problem and one of the common complications after MVD. In most cases, damage to the plexus can be prevented by monitoring the SSEPs generated in this region elicited by stimulation of the ulnar nerve and the median nerve.

12.4.3.1 Stimulation and Recording

Stimulation Sites Stimulation to the upper extremity is delivered to the median or ulnar nerve at the wrist. Stimulation to the lower extremity is delivered to the posterior tibial nerve at the ankle.

Stimulus Intensity and Rate Typical intensity values are 25 mA for arm stimulation and 50 mA for leg stimulation. The stimulus duration is set at 0.3 ms. A noninteger stimulation rat, such as 4.7/5.1 Hz, is used to avoid synchronization with power line interference.

Recording Electrodes and Band Pass The electrodes are placed on the scalp on specific locations according to the 10–20 international placement system used in clinical applications. For upper extremity stimulation, recordings are taken from the shoulder, cervical spine, and scalp. Three cortical channels (C'3-Fpz, C'4-Fpz, C'3-C'4), one cervical channel (Cs2-Fpz/Cs5-Fpz), and one peripheral channel (Erb's ipsilateral-contralateral) are needed for recording the median/ulnar nerve. Reference electrodes may be at the forehead or mastoid reference sites. The optimal low filter setting usually is 30 Hz. The optimal high filter setting is 1500–3000 Hz. The 60 and 50 Hz notch filter should be kept off. About 300–500 stimulations can produce a well-defined SSEP.

12.4.3.2 Intraoperative Interpretation

The recording channel Erbi-Erbc displays the first recorded potential as the Erb's point or N9. This consists of a negative upward deflection, occurring at about 9 ms after stimulation of the median/ulnar nerve at the wrist and represents the electronegativity caused by the electrical volley reaching the region of the EP (Chiappa 1990).

The recording channel Cs2-Fz/Cs5-Fz displays the second recorded potential, the cervicomedullary junction potential, represented by P/N13 complex. This potential is represented by a negative upward deflection, occurring at about 13 ms after the stimulation of the median nerve at the wrist.

The most important scalp-recorded component has a negative peak at about 20 cosec which is followed by a positive peak at about 25 ms, forming the N20-P25 complex. The N20 probably originates from the cortical area contralateral to the side of stimulation (C'3-Fpz/C'4-Fpz) (Fig. 12.3).

SSEPs have become an important adjunct in a wide range of surgical procedures. Thus, they are used for monitoring the function of the large-fiber sensory system during a variety of surgical procedures that could result in its damage. A greater than or equal to 50 % decrease in SSEP amplitude and/or a greater than or equal to 20 %

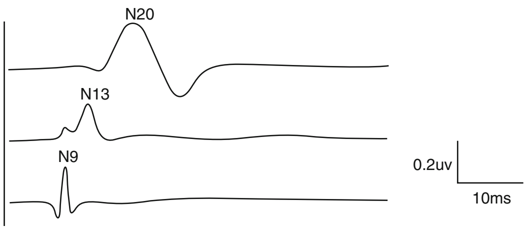

Fig 12.3 Somatosensory evoked potentials from median nerve stimulation are shown. Typical peaks are shown in each of the three recording channels

increase in latency is considered as significant change to produce potential postoperative neurological deficit. Amplitudes of the different components of evoked potentials are more susceptible to random changes than are the latencies of specific components.

During MVD surgery, the patient was placed in the park-bench position (lateral position with neck flexed and head rotated toward the floor). In order to get a better exposure and access, the upper shoulder and arm were depressed and fixed by means of tape attached to the shoulder and arm, while pronation and flexion of the lower arm can compress the ulnar nerve between the table and the cubital tunnel. Continuous intraoperative SSEP monitoring of ulnar/median nerve function intraoperatively as an indicator of brachial plexus function is a valid and useful technique to minimize intraoperative neurological injuries during MVD surgeries.

12.4.3.3 Anesthesia Requirements

Inhalational anesthetics, such as isoflurane, halothane, and enflurane, all reduce the amplitude and increase the latency of cortical components, and they are directly correlated to the concentration in which such agents are administrated in a dose-dependent fashion (Wang et al. 1985; Onofrj et al. 1990).

Intravenous agents, propofol, benzodiazepines, barbiturates, etomidate, ketamine, and opiates, all affect the amplitude and latency of SSEPs. The effects of various drugs most commonly used in anesthesia on the SSEPs are summarized and listed in Table 12.2.

Table 12.2 Effects of anesthetic agents on SSEP amplitude and latency

Agent	Amplitude	Latency
Nitrous oxide (N_2O)	↓	↑
Inhalational anesthetics	↓	↑
Propofol	–	↑
Barbiturates	↓	↑
Etomidate	↓	↑
Ketamine	–	↑
Opiates: morphine, fentanyl, alfentanil, sufentanil	–	↑
Benzodiazepines	↓	↑
Muscle relaxants	–	–
Hypotensive agents	↓	↑

Hypothermia might increase the latency and slightly decrease the amplitude of SSEPs, while hyperthermia will decrease the latency and decrease the amplitude. Severe hypotension can also result in a drastic decrease or even total loss of the cervical and cortical responses

12.4.4 Free-Run and Triggered Electromyography

Free-run EMG (fEMG) consists of recording spontaneous muscle activity. In intraoperative neurophysiology, it helps identify motor nerve depolarization from surgically driven irritation, hopefully before irreversible damage to these structures had occurred.

Triggered electromyographic (tEMG) activity can be recorded from a corresponding muscle after direct electrical stimulation of the motor nerve or nerve root. These signals are also known as compound muscle action potentials (CMAPs). Thus, it can be used to identify specific cranial nerves or nerve roots that may be difficult to distinguish from tumoral, fibrous, and fatty tissues and protect structural and functional integrity of cranial nerves and spinal roots.

12.4.4.1 Stimulation and Recording

Stimulation Sites No stimulation is required for fEMG recording. It is based entirely on recording spontaneous and detecting irritation-driven muscle activity, while an electrical stimulus directly on the nervous structures is required for triggered

EMG. For cranial nerve stimulation, monopolar technique is generally used. With bipolar or monopolar handheld probe, triggered EMG can be done by direct electrical stimulation of the nerve.

Stimulus Intensity and Rate The stimulation technique consists of delivering constant current, with repetitive square wave pulses of 0.1–0.2 ms, frequency 4 Hz, averaging 4–8 trials. Stimulus intensity for direct nerve or nerve root stimulation is gradually increased from 0 mA until an EMG response is seen up to a maximum of about 2 mA.

Recording Electrodes and Band Pass For both these methods, electrodes are placed in the target muscles corresponding to the nerve of interest. Most commonly, pairs of monopolar needles are used. The muscles typically used for monitoring cranial nerves are listed in the table. Relatively wide filter settings are used: low-frequency filter at 5 Hz and the high-frequency filter at 5 kHz. The sweep speed is usually set at 200 ms per division for recording continuous EMG and 2–5 ms/division for recording electrically evoked EMG potentials. The sensitivity is set at 50–200 uV per division.

12.4.4.2 Intraoperative Interpretation

Monitoring of both spontaneous and triggered EMG is strongly recommended also in microvascular decompressions. Continuous recording of spontaneous EMG can be used to provide early warnings of irritation of the nerve.

Free-Run EMG Activity

During free-run EMG monitoring, muscle activity is assessed continuously during portions of the procedure where the associated motor nerves are at risk. Manipulation of motor nerves may elicit depolarization of motor axons which then activates corresponding motor units within the monitored muscle. The recorded motor unit potentials (MUPs) may exhibit a wide range of patterns, which are characterized and interpreted to understand and predict the consequence of surgical actions that may elicit the activity. Making the EMG signal audible can greatly facilitate EMG monitoring, so that both the neurophysiologist and the surgeon can hear it. The following three criteria might be the signal of possible nerve injury: (1) sustained firing of a high-frequency train lasting for tens of seconds, (2) several large bursts of activity of complex morphology, and (3) sudden bursts of high-amplitude spikes followed by complete silence (Moller 1995). As a general rule, greater numbers and higher rates of recurrent MUPs correlate to higher levels of nerve irritation. But in the extreme cases, nerve injury may occur with a clean transaction of the nerve; there may be no EMG activity (Nelson and Vasconez 1995).

Triggered EMG Activity

Electrical stimulus is represented by CMAPs, which are a sum of motor action potentials that arise in several muscle fibers. During the surgery, the monitoring with EMG of muscles innervated by CNs VII, IX, and X can prevent facial palsies, dysphonia, and/or dysphagia (Kartush et al. 1991; Mishler and Smith 1995; Schlake et al. 1999; Harper 2004; Minahan and Mandir 2011; Singh and Husain 2011). Though these CN palsies are usually transient, they are directly attributable to these nerves' cauterization, pulling, retraction, or section that can happen during these procedures (Habeych et al. 2014). The identity of the cranial nerve can be resolved by simply determining the muscle on which a response has been obtained. If the same recording electrode detects activity from a muscle corresponding to two different nerves, then the latency of the response will determine its origin, for example, identifying the trigeminal from the facial nerve, since stimulation of the trigeminal nerve elicits a CMAP onset latency ranging between 3.5 and 5 ms (Moller 2011), while facial nerve stimulation generally produces a CMAP with an onset latency between 6 and 8 ms (Fig. 12.4).

During a surgery of CPA tumor resection, tEMG can be used to identify and thus avoid damage to the motor branch of the nerve which must be preserved. A baseline threshold should

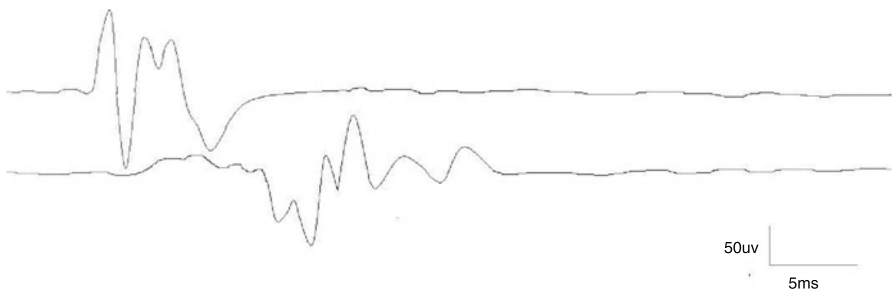

Fig 12.4 *Upper curve*: EMG potentials recorded from electrodes placed in the masseter muscles. *Lower curve*: EMG potentials recorded from electrodes placed in the orbicularis oculi muscles

be taken before the dissection. In addition to tEMG, continuous recording of fEMG can be used to provide early warnings of mechanical or thermal irritation of the nerve. Periodic stimulation of the nerve and recording of tEMG can inform the surgeon of the functional integrity of the nerve at any given point in time and then at the end of the surgery, by stimulating the nerve proximal to the tumor first. A prolonged reduction in response amplitude that is not due to perisurgical events, such as an increased level of muscle relaxation, is associated with an increased likelihood of postoperative muscle weakness (Zouridakis and Papanicolaou 2000; Moller 2011).

12.4.4.3 Anesthesia Requirements

The level of muscle relaxation or pharmacologically induced paralysis is the most crucial factor affecting EMG monitoring. It is recommended that the patient is free of their effects during the time when EMG monitoring is performed, or the neuromuscular blocking agents should be kept to the minimum that the clinical situation allows. Inhaled anesthetic agents have little or no effect on EMG monitoring. Depth of muscle relaxation is monitored by delivering a train of four electrical stimuli, with an intensity of about 25 mA, usually to the median or facial nerve, and measuring the resulting number of muscle contractions. Zero twitches indicate complete paralysis, whereas at least three twitches indicate that the patient remains minimally relaxed or practically no paralysis (Zouridakis and Papanicolaou 2000). The effects of anesthesia and of the patient's blood pressure and temperature must all be considered when applying EMG in the operating room.

12.4.5 Abnormal Muscle Response

In 1985, Moller and Jannetta first showed that in patients with hemifacial spasm, stimulation of one branch of the facial nerve may result in the activation of facial muscles innervated by other branches, due to the hyperexcitability of the facial nerve. This abnormal muscle response has been termed "lateral spread" or "lateral spread response" (LSR) and is thought to be related to ephaptic transmission, though the specific mechanism of lateral spread is unclear. Due to the fact that LSR disappears instantly in most of the patients when the offending vessel is moved off the facial nerve, monitoring the abnormal muscle response can guide the surgeon during MVD which results in a better postoperative outcome (Moller and Jannetta 1987).

Neuro-monitoring of the lateral spread response and, more specifically, its disappearance may help predict short- and long-term success of microvascular decompression (MVD) for hemifacial spasm.

12.4.5.1 Stimulation and Recording

Stimulation Sites Stimulation needle electrodes are most commonly placed over the temporal branch or the marginal mandibular branch of the facial nerve (Moller 1991).

Stimulation Intensity and Rate A single constant current stimulus of 0.1–0.2 ms duration, at a stimulating rate of 1 Hz, is used for eliciting lateral spread. Usually, a stable AMR was recorded at a stimulation intensity level of 5–15 mA. During MVD, the threshold intensity is adjusted for continuously eliciting the lateral spread. If AMR disappeared, the intensity was increased up to 50 mA for a few seconds in order to confirm the permanent LSR disappearance (Moller and Jannetta 1986).

Recording Electrodes and Band Pass Recording needles are inserted 0.5–1 cm apart subcutaneously into the mentalis muscle if the temporal branch of the facial nerve is stimulated or into the orbicularis oculi muscles if the marginal mandibular branch is stimulated (Fig. 12.5).

12.4.5.2 Intraoperative Interpretation

With intraoperative monitoring, an AMR wave with a latency of around 10 ms after stimulation was recorded. The baseline threshold for eliciting the AMR is determined, and stimulation may proceed near this level. When the offending vasculature is moved off the facial nerve, the LSR is known to disappear or become markedly attenuated (Thirumala et al. 2011) (Fig. 12.6). However, the AMR may dissipate before the MVD is performed as sometimes occurs, for instance, when the dura is opened. It is suggested that stimulation intensity and/or rate should be increased in these circumstances to reestablish the presence of AMR (Sekula et al. 2009).

The practical value of AMR disappearance as a method to evaluate MVD efficacy is still controversial (Joo et al. 2008). There are some patients where AMR does not fully disappear despite an apparent effective decompression and they are free of spasm with a delay up to 1 year after surgery. However, in most cases, LSR monitoring is an effective tool to predict outcome after MVD for HFS (Kong and Park 2007; Kim et al. 2010; Thirumala et al. 2011; Ying et al. 2011).

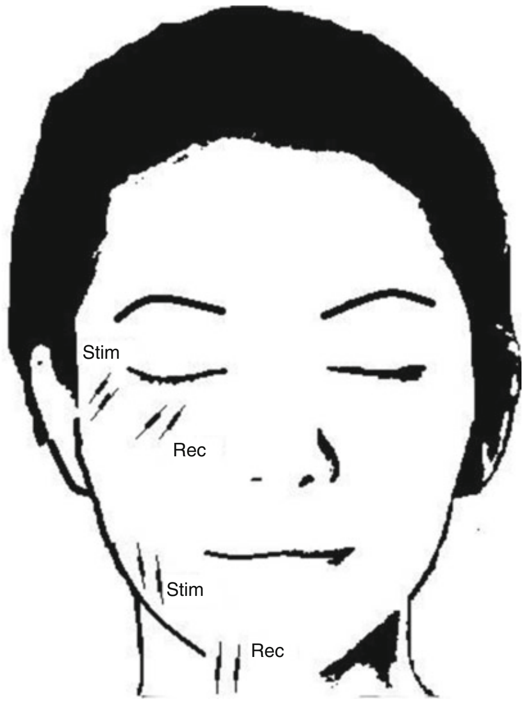

Fig 12.5 Placement of stimulating and recording electrodes for monitoring the abnormal muscle response in patients with hemifacial spasm

12.4.5.3 Anesthesia Requirements

As AMR is a kind of triggered electromyographic response, the level of muscle relaxation played a very important role in the monitoring. No muscle relaxant is used after the induction of anesthesia.

12.4.6 ZLR

ZLR was first reported by Zheng et al. (2012) for intraoperative monitoring of HFS. It is useful when an AMR is absent before decompression or persists after all vascular compressions are properly treated. Particularly, the ZLR response may help neurosurgeons determine the real culprit when multiple offending vessels exist.

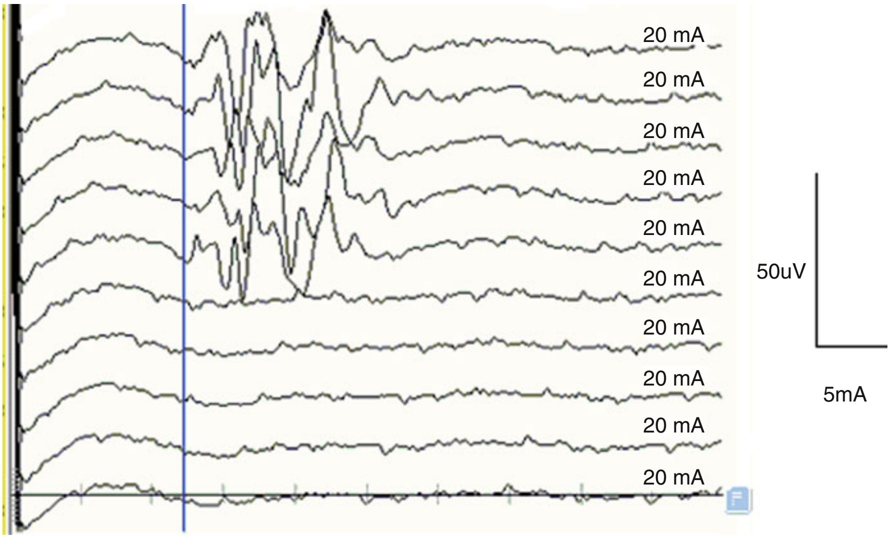

Fig 12.6 Typical changes of AMR during MVD for HFS

12.4.6.1 Stimulation and Recording

Stimulation Sites The stimulating electrode was placed on the offending artery wall near the compression site (within 5 mm) during MVD for hemifacial spasm (Zheng et al. 2012).

Stimulation Intensity and Rate A single constant current stimulus of 0.1–0.2 ms duration, at a stimulating rate of 1 Hz, is used for eliciting ZLR. The intensity of stimulation is 1–2 mA.

Recording Electrodes and Band Pass The ZLR was recorded from the orbicularis oculi, orbicularis oris, and mentalis muscles. Needle electrodes are used to record ZLR from the facial muscles including orbicularis oculi, orbicularis oris, and mentalis. Filter settings are the same as that of the AMR.

12.4.6.2 Intraoperative Interpretation

The ZLR looked similar to an AMR. The latency of ZLR is 7.3 ± 0.8 ms, which is significantly shorter than the AMR latency (Fig. 12.7). The ZLR can only be detached on the offending artery, when more than one artery compressed the facial nerve. In the majority of patients, in which one offending vessel compressed the facial nerve at one offending site, ZLR and AMR provided the same information for the surgery: both ZLR and AMR disappeared immediately when the offending artery is removed from the facial nerve. But when AMR was absent from the beginning or persisted after the offending vessel was transposed with Teflon sponges, ZLR played a crucial role to identify whether there was sufficient decompression (Yang et al. 2014). The combination of AMR and ZMR might provide more useful information than does the AMR alone, and ZLR may be the only useful intraoperative EMG for MVD surgery in some cases (Zheng et al. 2012).

12.4.6.3 Anesthesia Requirements

The anesthesia requirements of ZLR monitoring are the same as that of AMR. No muscle relaxant is supposed to be used after the induction of anesthesia.

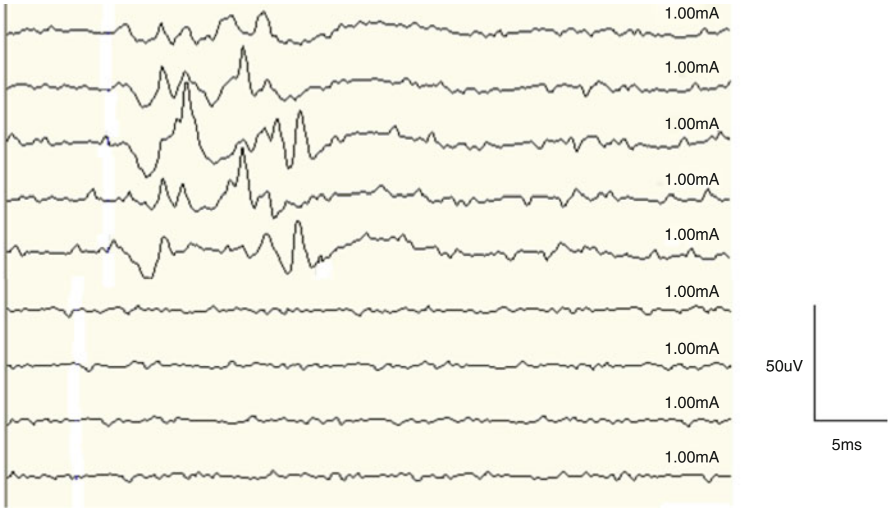

Fig 12.7 ZLR recorded from the facial muscles when stimulating the offending artery wall

12.4.7 Facial F Wave

The F wave is an antidromic pulse that propagates to an alpha motor neuron in the anterior horn of the spinal cord and then returns orthodromically down the same axon. It is a standard electrophysiological means to reveal lesions in the proximal segments of peripheral nerves.

The facial F-wave findings in various diseases involving the intracranial and intracanalicular portion of the nerve have recently been reported to demonstrate the diagnostic utility of this method (Wedekind and Klug 1998).

12.4.7.1 Stimulation and Recording

Stimulation Sites The stimulating electrodes are placed in proximal position over the zygomatic branch of the facial nerve.

Stimulus Intensity and Rate The facial nerve was stimulated with constant current rectangular monophasic pulses (duration of 0.1–0.2 ms) transmitted transcutaneously (for extraoperative studies) or by subdermal needle electrodes (for intraoperative measurements). Stimulation frequency was 1 Hz (Wedekind and Klug 2003). The stimulation strength was set to supramaximum to elicit stable M waves with minimum stimulus intensity (usually 3–10 mA).

Recording Electrodes and Band Pass For recording of muscle activity, silver chloride cup electrodes filled with conducting gel were placed on both alae nasi to record the compound action potential of the pars alaris of the nasal muscle. These active electrodes were referenced to an electrode on the nose tip or the glabella (Wedekind and Klug 2000; Wedekind et al. 2001). F waves, which varied according to each stimulus, were analyzed for F/M amplitude ratio (i.e., the percentage of the peak to peak amplitude of the F wave to the M wave) and duration (from the initial deflection from the baseline to the final return of the F wave) (Ishikawa et al. 1996). Recordings were passed through a preamplifier and amplifier (100 u/div) and then filtered (band pass of 20 and 3000 Hz) without averaging.

12.4.7.2 Intraoperative Interpretation

The F waves are useful indicators of lower motor neuron excitability (Hai and Pan 2007). In the ipsilateral mentalis muscles, the F wave through stimulating the marginal mandibular branch of the facial nerve is also an antidromic pulse that propagates to the facial motor nucleus and returns orthodromically down the same axon. Thus, the F wave in facial muscles may indicate the excitability of the facial motor nucleus (Fig. 12.8).

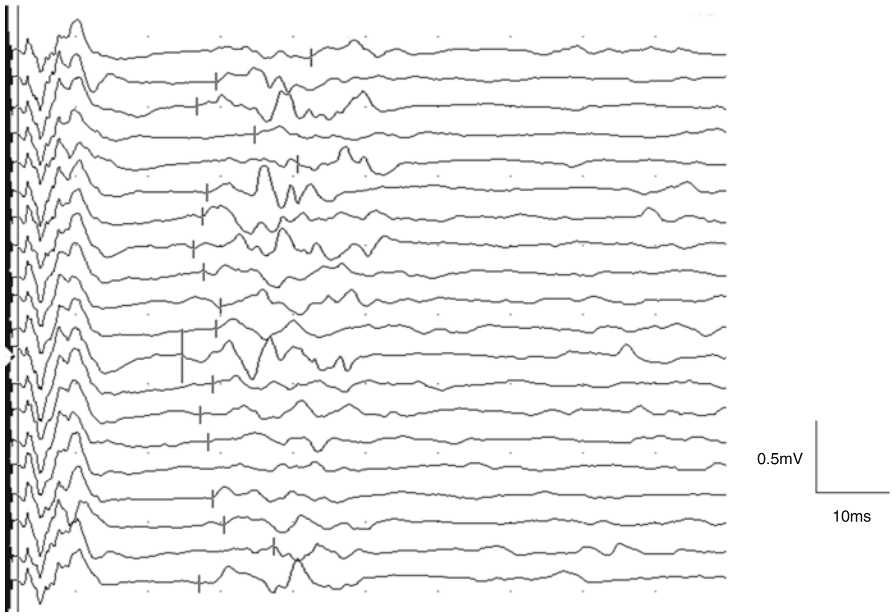

Fig 12.8 Typical F wave recorded from facial nerve

Electrophysiological study demonstrated that the F-wave appearance is more persistent in patients with HFS. Neurophysiological investigations have been done in patients with HFS, and F wave has been recorded in facial muscles before and after MVD (Moller 1991; Ishikawa et al. 1997). It has been shown that there are significant increased F waves in the amplitude, duration, and frequency in patients with HFS (Hai and Pan 2007). Immediate changes in excitability on facial motor nucleus are observed by monitoring changes in F-wave elicitability. These responses are monitored together with LSR, and there is evidence that whenever LSR disappears, F wave disappears as well (Fernandez-Conejero et al. 2012).

Intraoperative recordings of facial nerve F waves recorded from nasal muscles have been studied as an effective measure of facial nerve function in surgery. In the surgery of CPA tumors, facial F-wave monitoring provides continuous and valid real-time information concerning the functional status of the nerve under the strain of dissection. Intraoperative F wave changes closely parallel the actual strain exerted on the nerve. Intraoperative monitoring of F waves further provides a feature (transient loss of the F wave) which heralds an imminent danger of severe facial dysfunction to occur. Wedekind et al. (2001) have investigated the use of F waves during vestibular schwannoma resection and report that a permanent loss of F-wave results in 91 % sensitivity and 100 % specificity for poor outcome. In addition, the transient loss of signals was detected more frequently in patients with moderate outcomes. Facial F-wave recording provides valuable information on the functional status of the nerve intra- and extraoperatively (Wedekind and Klug 2003).

12.4.7.3 Anesthesia Requirements

The intraoperative use of facial nerve F waves is limited by its sensitivity to anesthesia and its absence in some healthy adults (Wedekind et al. 2001; Wedekind and Klug 2003).

12.4.8 Blink Reflexes

In 1952, Kugelberg was the first to report the presence of two electrically induced blink reflex (BR) components, R1 and R2 (Kugelberg 1952).

The R1 response corresponds to the oligosynaptic reflex arc, which includes trigeminal afferents, brain stem connections between the sensory part of the trigeminal nucleus and the motor nucleus of the facial nerve, the facial nerve proper, and the orbicularis oculi muscle. The R2 component is more complex in its central, polysynaptic connections within the brain stem, but it has the same afferent and efferent pathways as the R1.

The blink reflex would be suitable for continuous monitoring of the function of both trigeminal and facial nerve intraoperatively. Unfortunately, BR was typically absent in anesthetized patients (Mourisse et al. 2004). It was recently shown that it is possible to elicit the blink reflex in surgically anesthetized patients using a train of four to seven stimulus impulses applied to the supraorbital nerve when suitable modern anesthesia techniques are used (Deletis et al. 2009). Thus, the use of this test for the use for intraoperative neuro-monitoring appears feasible.

12.4.8.1 Stimulation and Recording

Stimulation Sites Stimulation of the supraorbital nerve was performed using a pair of electroencephalographic needle electrodes inserted subcutaneously over the supraorbital nerve.

Stimulus Intensity and Rate Four to seven rectangular constant current stimuli with an interstimulus interval (ISI) of 2 ms, intensity of 20–40 mA, and train repetition rate of 0.4 H z were used.

Recording Electrodes and Band Pass Recording was done with needle electrodes identical to those used for stimulation. The electrodes were inserted in the low lateral part of the orbicularis oculi muscle ipsilateral and contralateral to the stimulating side. Recordings were made by using a 50-ms epoch and band-pass digital filters of 70 and 1219 Hz. Recording of the BR was attempted after intubation, in the middle of surgery, and after starting skin closure (Deletis et al. 2009).

12.4.8.2 Intraoperative Interpretation

Characteristically, an electrical stimulus on the supraorbital nerve (VI) induces two recordable responses in the orbicularis oculi muscles: an early one, the so-called R1, ipsilateral to the stimulated side, and a later one, the R2, which is bilaterally expressed. The R2 response ipsilateral to the stimulus is frequently cited as R2i, and the R2c is the one obtained on the contralateral side, also denominated "consensual response," in analogy to the photomotor pupillary reflex (Esteban 1999).

The R1 component of the BR has a rather stable latency of approximately 10 ms. R2 typically shows relative variable latencies and larger magnitudes than R1 and its threshold is lower (Sanes et al. 1982).

In symptomatic trigeminal pains, the trigeminal reflexes have a very high sensitivity, probably because they allow examination of all three divisions. The most sensitive reflex is the R1 of the blink reflex (Cruccu et al. 1990). Mild reflex abnormalities occur occasionally, but in most patients with idiopathic trigeminal neuralgia, all reflexes are normal (Aramideh 2002).

BR can be also used to evaluate hyperexcitability of the facial motor nucleus in patients with HFS by measuring the latency and duration of the R2 component as well as the R1 and R2 recovery curves (Valls-Sole and Tolosa 1989). A larger R1 and R2 response is usually obtained on stimulating the affected side, rather than the contralateral side (R2c), or after stimulating the unaffected side, the ratio R2c/R2 may be increased (Eekhof et al. 2000; Oge et al. 2005; Sekula et al. 2009). After decompression of the facial nerve during the MVD surgery for HFS, it is necessary to increase the number of stimuli within the train in order to reproduce BR. It is presumed that this phenomenon results in the immediate decrease in excitability of the facial motor nucleus after an effective MVD (Fernandez-Conejero et al. 2012).

The possibility to achieve continuous monitoring of the sensory part of the trigeminal nerve, brain stem, and facial nerve is a further important development.

12.4.8.3 Anesthesia Requirements

It is feasible to record the BR in patients under general anesthesia using low doses of desflurane or sevoflurane during surgery. If total intravenous anesthesia is used, boluses of propofol should be avoided, because they prevent elicitation of the BR. Administration of muscle relaxants should also be avoided.

12.4.9 Motor Evoked Potentials

Transcranial electrical stimulation was first applied to the human brain by Merton and Morton (1980). It can be generated by electrical stimulation of the cortex or the spinal cord. It involves applying an electrical current with the purpose of depolarizing the corticospinal system proximal to the level of the surgery, above its threshold. This method assesses the integrity of the motor pathways, from the cortex to the muscles. The method was found to be practical and effective intraoperatively, and it is now widely accepted as necessary in the neurosurgical field (MacDonald 2002; Motoyama et al. 2011). For neurophysiological IOM of the motor pathways, the use of MEPs triggered by electrical cortical stimulation is a technique done successfully under anesthesia.

12.4.9.1 Stimulation and Recording

Stimulation Sites The standard 10–20 EEG electrode placement is used. Scalp electrodes are often placed more lateral than the standard montage for spinal surgeries (Fernandez-Conejero et al. 2012): C3-Cz for left hemispheric stimulation and C4-Cz for right hemispheric stimulation (Dong et al. 2005). The use of a Cz cathode may help to minimize the chance of extracranial activation of the facial CSound stimulus is delivered through miniature.

Stimulus Intensity and Rate Transcranial stimulation may be constant voltage (range of 180–600 V) or constant current (range of 50–220 mA) with varying durations of 0.5–3 ms and interstimulus interval of 1–5 ms, typically using three or more pulses with a train repetition rate of 2 Hz

Table 12.3 Cranial nerves and the corresponding muscles used in IOM

Cranial nerve	Nerve name	Muscles
II	Oculomotor	Inferior rectus, inferior oblique
IV	Trochlear	Superior oblique
V	Trigeminal	Masseter, temporalis
VI	Abducens	Lateral rectus
VII	Facial	Frontalis, orbicularis oculi, nasalis, orbicularis oris, mentalis
IX	Glossopharyngeal	Lateral soft palate
X	Vagus	Vocal cords, cricothyroid
XI	Accessory	Trapezius/ sternocleidomastoid
XII	Hypoglossal	Tongue/genioglossus

(Akagami et al. 2005; Dong et al. 2005; Sala et al. 2007; Fukuda et al. 2008; Acioly et al. 2010).

Recording Electrodes and Band Pass Electrodes are placed in the target muscles corresponding to the nerve of interest. Most commonly, pairs of monopolar needles are used. The muscles typically used for monitoring cranial nerves are listed in Table 12.3. Filter settings vary between 5 and 10 kHz (Akagami et al. 2005; Dong et al. 2005; Sala et al. 2007; Fukuda et al. 2008; Acioly et al. 2010).

12.4.9.2 Intraoperative Interpretation

Preservation of postoperative facial nerve function is an important goal of microvascular decompression. To estimate postoperative cranial nerve function, MEP monitoring was reported to be of value (Fukuda et al. 2008; Matthies et al. 2011). It facilitates observation of the function of both the first and second motor neuron and helps to predict postoperative nerve function. However, MEP cannot be used for continuous intraoperative monitoring because of body movement artifacts. Operative manipulations must be stopped during recording of the MEP (MacDonald 2002; Motoyama et al. 2011).

MEP can provide a beneficial impact on the prevention of paraplegia and paralysis during surgeries in which the motor pathways may be compromised (Kodama et al. 2014) The intraoperative increase in stimulation threshold and decrease in amplitude were closely correlated to postoperative nerve dysfunction (Cosetti et al. 2012; Macdonald et al. 2013; Sarnthein et al. 2013).

More recently, MEPs have also been used during MVD as a method to identify and avoid lesions to the facial nerve when manipulating the vessels compressing the facial nerve. Facial CMAPs in TcMEPs appear at a short latency around 15 milliseconds (Fukuda et al. 2008). However, the most sensitive criterion for intraoperative interpretation is based only on amplitude. Fujiki et al. suggest that a decline ≥35 % relative to baseline amplitude is associated with minimum transient postoperative motor deficits (Fujiki et al. 2006; Fukuda et al. 2008).

Fernandez-Conejero et al. (2012) reported that MEP monitoring in patients with HFS has remarkable characteristics due to the hyperexcitability of the facial nerve and facial motor nucleus. The FCoMEPs are continuously recorded before, during, and after MVD together with LSR. The major excitability changes observed in FCoMEPs are increased by the number of stimuli required to obtain responses or intensity of current compared to the baselines. Thus, TcMEPs have also been investigated as adjuvant monitoring during MVD for hemifacial spasm (Fig. 12.9).

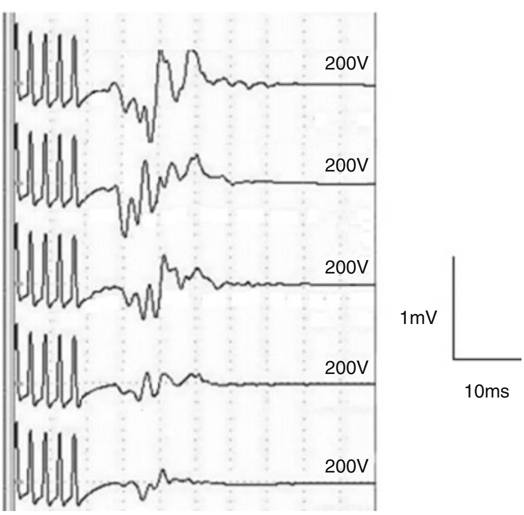

Fig 12.9 It takes a short train stimulus of 200 V to elicit MEP before surgery. After MVD is completed, the amplitude of MEP decreased significantly

12.4.9.3 Anesthesia Requirements

In general anesthetic techniques should be used with minimized inhalational agents, such as nitrous oxide and isoflurane (Kalkman et al. 1993), and minimized neuromuscular blockade. Anesthesia techniques using a combination of less than 50 % nitrous oxide and narcotics, etomidate, or ketamine allow the recording of reliable MEPs (Kalkman et al. 1993).

12.5 Case

The patient was diagnosed as a typical left HFS based on the clinical history of typical symptoms and electrophysiological examination. BAEP, AMR, ZLR, and SSEPs were recorded during the MVD operation.

The operation was performed under general anesthesia. No muscle relaxant is supposed to be used after the induction of anesthesia. To ensure the integrity of the stimulating and recording electrodes, an initial recording was made as baseline following induction, before the patient had been positioned. After the patient was positioned, another SSEP was recorded. Then, subsequent recordings continued throughout the case.

During the entire operation, the root exit zone (REZ) of the facial nerve was compressed by both the vertebral artery (VA) and anterior inferior cerebellar artery (AICA) (a). A typical AMR was recorded on this operation (b). The Z-L response (ZLR) was identified from AICA (c, d), but not from VA (e, f). Both AMR and ZLR disappeared after decompression (g, h, i). The patient achieved immediate "excellent" resolution of spasms after surgery.

The latency of wave V and the IPL I–V was found delayed when the VIIIth nerve was retracted. Then the surgeon was informed and the retracting stopped. The BAEPs came back to normal until the end of the surgery (j).

This patient achieved excellent resolution of spasm. No significant change was recorded from SSEPs. Postoperatively, there were no complications observed, and the patient denied any symptoms such as hearing loss, tingling, or numbness of upper extremities (Fig. 12.10).

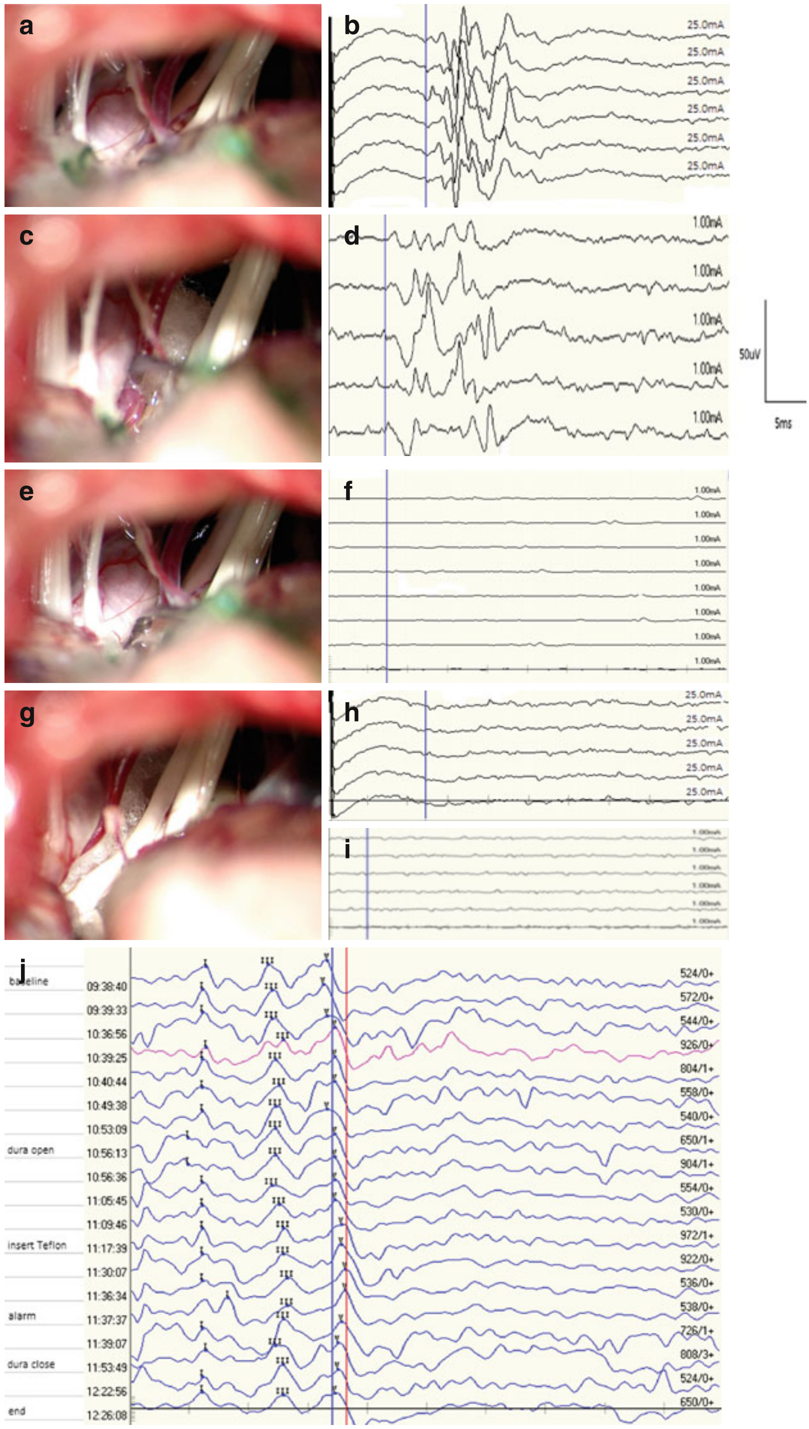

Fig 12.10 Electrophysiological monitoring change and intraoperative pictures of the typical HFS patient

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