2

Basis of Intraoperative Neurophysiological Monitoring

INTRODUCTION

Intraoperative neurophysiological monitoring is often associated with reducing the risk of postoperative neurological deficits in operations where the nervous system is at risk of being permanently injured. While the main use of electrophysiological methods in the operating room may be for reducing the risk of postoperative neurological deficits, electrophysiological methods are now in increasing use for other purposes. For example, electrophysiological methods are now regarded a necessity for guidance in placement of electrodes for deep brain stimulation (DBP) or for making lesions in specific structures for treating movement disorders and pain. Intraoperative electrophysiological recordings can also help the surgeon in carrying out other surgical procedures. Finding specific neural tissue such as cranial nerves or specific regions of the cerebral cortex are examples of tasks that are included in the subspecialty of intraoperative neurophysiological

From: *Intraoperative Neurophysiological Monitoring: Third Edition*,
By A.R. Møller, DOI 10.1007/978-1-4419-7436-5_2,

monitoring. Neurophysiological methods are increasingly used for diagnostic support in operations such as those involving peripheral nerves. In certain operations, intraoperative neurophysiology can increase the likelihood of achieving the therapeutical goal of an operation. Intraoperative neurophysiological recordings have shown to be of help identifying the offending blood vessel in a cranial nerve disorder (hemifacial spasm, HFS).

REDUCING THE RISK OF NEUROLOGICAL DEFICITS

The use of intraoperative neurophysiological monitoring to reduce the risk of loss of function in portions of the nervous system is based on the observation that the function of neural structures usually changes in a measurable way before being permanently damaged. Reversing the surgical manipulation that caused the change within a certain time will result in a recovery to normal or near normal function, whereas if no intervention is taken, there will be a risk of permanent postoperative neurological deficit.

Surgical manipulations such as stretching, compressing, or heating from electrocoagulation are insults that can injure neural tissue. Ischemia, caused by impairment of blood supply due to surgical manipulations or intentional clamping of arteries, may also result in permanent (ischemic) injury to neural structures causing a risk of noticeable postoperative neural deficits.

The effect of such insults represents a continuum; at one end, function decreases during the time of the insult, and at the other end of this continuum, nervous tissue is permanently damaged, and normal function never recovers and results in permanent postoperative deficits. Between these extremes, there is a large range over which recovery may occur either totally or partially. Thus, up to a certain degree of injury, there can be total recovery, but thereafter, the neural function may be affected for some time. Following a more severe injury, the recovery of normal function not only takes a longer time, but the final recovery would be partial with the degree of recovery depending on the nature, degree, and duration of the insult.

Injuries acquired during operations that result in a permanent neurologic deficit will most likely reduce the quality of life for the patient for many years to come and maybe for a lifetime. It is, therefore, important that the person who is responsible for interpreting the results of monitoring is aware that the neurophysiologist has a great degree of responsibility, together with the surgeon and the anesthesiologist, in reducing the risk of injury to the patient during the operation.

Techniques for Reducing Postoperative Neurological Deficits

The general principle of intraoperative neurophysiological monitoring is to apply a stimulus and then to record the electrical response from specific neural structures along the neural pathway that are at risk of being injured. This can be performed by recording near-field evoked potentials by placing a recording electrode on a specific neural structure that becomes exposed during the operation, or, as more commonly done, by recording far-field evoked potentials from, for instance, electrodes placed on the surface of the scalp.

Intraoperative neurophysiological monitoring that is done for the purpose of reducing the risk of postoperative neurological deficits makes use of relatively standard and well-developed methods for stimulation and recordings of electrical activity in the nervous system. Most of the methods that are used in intraoperative neurophysiological monitoring are similar to those that have been used in the physiologic laboratory and in the clinical testing laboratory for many years.

Sensory System. Intraoperative neurophysiological monitoring of the function of sensory systems has been widely practiced since the middle of the 1980s. The earliest uses of intraoperative neurophysiological monitoring of sensory systems were modeled after the clinical practice of recording sensory evoked potentials for diagnostic purposes.

Sensory systems are monitored by applying an appropriate stimulus and recording the response from the ascending neural pathway, usually by placing recording electrodes on the surface of the scalp to pick up evoked far-field potentials from nerve tracts and nuclei in the brain (far-field responses).

It has been mainly somatosensory evoked potentials (SSEP) and auditory brainstem responses (ABR) that have been recorded in the operating room for monitoring the function of these sensory systems for the purpose of reducing the risk of postoperative neurological deficits. Visual evoked potentials (VEP) are also monitored in some operations. When intraoperative neurophysiological monitoring was introduced, it was first SSEP that were monitored routinely (*1*), followed by ABR (*2–4*).

While the technique used for recording sensory evoked potentials in the operating room is similar to that used in the clinical diagnostic laboratory, there are important differences. In the operating room, it is only changes in the recorded potentials that occur during the operation that are of interest, while in the clinical testing laboratory, the deviation from normal values (laboratory standard) are important measures.

Another important difference is that results obtained in the operating room must be interpreted instantly, which places different demands on the personnel who are responsible for intraoperative neurophysiological monitoring than those working in the clinical laboratory. In the operating room, it is sometimes possible to record evoked potentials directly from neural structures of sensory pathways (near-field responses) when such structures are exposed during an operation.

The use of evoked potentials in intraoperative neurophysiological monitoring for the purpose of reducing the risk of postoperative permanent sensory deficits is based on the following:

1. Electrical potentials can be recorded in response to a stimulus.
2. These potentials change in a noticeable way before permanent damage occurs from surgical manipulations of heating from electrocoagulation.
3. Proper surgical intervention, such as reversal of the manipulation that caused the change, will reduce the risk that the observed change in function develops into a permanent neurological deficit or, at least, will reduce the degree of the postoperative deficits.

Motor Systems. Intraoperative neurophysiological monitoring of the facial nerve was probably the first motor system that was monitored (*5, 6*). Systematic monitoring came later (*7, 8*). The introduction of skull base surgery in the beginning of the 1980s (*9*) caused an increased demand for monitoring of other cranial systems, and the use of monitoring for many cranial motor nerves spread rapidly (*10, 11*). Intraoperative neurophysiological monitoring of spinal motor systems was delayed because of technical difficulties, mainly in eliciting recordable evoked motor responses to stimulation of the motor cortex in anesthetized patients. After these technical obstacles in activating descending spinal motor pathways were resolved in the 1990s, intraoperative neurophysiological monitoring of spinal motor systems gained widespread use (*12*). Monitoring of cranial nerve motor systems commonly relies on electrical stimulation of specific cranial motor nerves while recording electromyographic (EMG) potentials from muscles that are innervated by the motor nerves in question. Monitoring of spinal motor systems makes use of stimulation of the motor cortex (or cortices) by transcranial electrical stimulation or (rarely) by transcranial magnetic stimulation while recording directly from the descending motor pathways of the spinal cord or EMG potentials from specific muscles (Chaps. 10 and 11).

Peripheral Nerves. Monitoring of motor nerves is often accomplished by observing the electrical activity that can be recorded from one or more of the muscles that are innervated by the motor nerve or motor system that is to be monitored (evoked EMG potentials). The respective motor nerve may be stimulated electrically or by the electrical current that is induced by a strong magnetic impulse (magnetic stimulation). Recordings of muscle activity that is elicited by mechanical stimulation of a motor nerve or by injury to a motor nerve are important parts of many forms of monitoring of the motor system. Such muscle activity is monitored by the continuous recording of EMG potentials ("free running EMG"). When such activity is made audible, it can provide important feedback to the surgeon, and the surgeon can then modify his/her operative technique accordingly.

Monitoring peripheral nerves intraoperatively may be done by electrically stimulating the nerve in question at one point and recording compound action potentials (CAP) at a different location. Changes in neural conduction that may occur between these two locations will result in changes in the latency of the CAP and/or in the waveform and amplitude of the CAP. The latency of the CAP is inversely related to conduction velocity, and decreased conduction velocity is a typical sign of injury to a nerve. The latency of the recorded CAP typically increases as a result of many kinds of insults to a nerve and its waveform changes.

Interpretation of Neuroelectric Potentials

The success of intraoperative neurophysiological monitoring depends greatly on the correct interpretation of the recorded neuroelectric potentials. In most situations, the usefulness of intraoperative neurophysiological monitoring depends on the person who watches the display, makes the interpretation, and decides what information should be given to the surgeon. It is, therefore, imperative for success in intraoperative neurophysiological monitoring that the person who is responsible for the monitoring be well trained. It is also important that he/she is familiar with the different steps in the operation, the kind of anesthesia used, and well informed in advance about the patient who is to be monitored.

It is important that information about changes in recorded potentials be presented to the surgeon in a way that contributes specific descriptive details that the surgeon will find useful and actionable. Surgeons are not neurophysiologists, and the knowledge about neurophysiology varies among surgeons. Neurophysiologists who provide results of monitoring to the surgeon must, therefore, present their skilled interpretation of the recorded potentials. The surgeon may not always appreciate data, such as latency values, because the surgeon may not understand what such data represent. Monitoring is of no value if the surgeon does not take action accordingly. If the surgeon does not understand what the information provided by the neurophysiologist means, then there is little chance that he/she will take appropriate action.

Correct and prompt interpretation of changes in the waveforms of the recorded potentials is essential for such monitoring to be useful. The far-field potentials, such as ABR, SSEP, and VEP, are often complex and consist of a series of peaks and troughs that represent the electrical activity that is generated by successively activated nerve tracts and nuclei of the ascending neural pathways of the sensory system. Exact descriptions of the implications of the changes in such potentials that may occur as a result of various kinds of surgical insults, therefore, requires thorough knowledge about the anatomy and physiology of the systems that are monitored and how the recorded potentials are generated.

The most reliable indicators of changes in neural function are changes (increases) in the latencies of specific components of sensory evoked potentials, but surgically induced insults to nervous tissue often cause changes in the amplitude of sensory evoked potentials as well.

It must be remembered that the recorded sensory evoked potentials do not measure the function (or changes in function) of the sensory system that is being tested. For example, there is no direct relationship between the change in the ABR and the change in the patient's hearing threshold or change in speech discrimination. This is one reason why it has been difficult to establish guidelines for how much evoked potentials may vary during an operation without presenting a noticeable risk for postoperative deficits.

Interpretation of sensory evoked potentials is based on knowledge about the anatomical location of the generators of the individual components of SSEP, ABR, and VEP in relation to the structures that are being manipulated in a specific operation. Interpretation of sensory evoked potentials also depends on the processing of the recorded potentials; for example, filters or filtering techniques of various kinds that are used affect the waveform of the potentials.

The amplitude of these sensory evoked potentials is smaller than the background noise (ongoing brain activity such as electroencephalographic potentials) and electrical noise that enters recording amplifiers from the environment (see Chap. 18). It is, therefore, necessary to use signal averaging to enhance the signal-to-noise ratio of far-field potentials such as sensory evoked potentials. Signal averaging (adding the responses to many stimuli) is based on the assumption that the responses to every stimulus are identical and that they always occur at the same time following stimulation. Since the sensory evoked potentials that are recorded in the operating room are likely to change during the time that responses are being averaged, the averaging process may produce unpredictable results.

These matters are important to take into consideration when interpreting sensory evoked potentials. Signal averaging and filtering are discussed in detail in Chap. 18. This chapter also discusses different ways to reduce the time necessary to obtain an interpretable recording. The specific techniques that are suitable for intraoperative neurophysiological monitoring of the auditory, somatosensory, and visual systems are dealt with in detail in Part II (Chaps. 6, 7, and 8, respectively).

In some instance, it is possible to record evoked potentials from the structures that actually generate the recorded potentials in question (near-field potentials). Such potentials often have sufficiently large amplitudes allowing observation of the potentials directly without signal averaging. If it is possible to base the intraoperative neurophysiological monitoring on recording of evoked potentials directly from an active neural structure (nerve, nerve tract, or nucleus), little or no signal averaging may be necessary because the amplitudes of such potentials are much larger than those of far-field potentials such as the ABR and SSEP. Such near-field potentials can often be viewed in real time on a computer screen or after only a few responses have been averaged. These matters are also discussed in detail in the chapters on sensory evoked potentials (Part II).

The design of the monitoring system, the way the recorded potentials are processed, and the way the recorded potentials are displayed are important factors in facilitating proper interpretation of the recorded neuroelectric potentials (see Chap. 17). The proper choice of stimulus parameters and the selection of the location along the nervous pathways where the responses are recorded also facilitate prompt interpretation of recorded neuroelectric potentials.

When recording EMG potentials, it is often advantageous to make the recorded response audible (*7, 13*) so that the neurophysiologist who is responsible for the monitoring and the surgeon can hear the response and make his or her own interpretation. Still, the possibilities to present the recorded potentials directly to the surgeon are currently few, and it is questionable whether it would be advantageous. Few surgeons are physiologists, and most surgeons prefer the results of monitoring to be presented in a descriptive form rather than raw data.

The importance of being able to detect a change in function as soon as possible cannot be emphasized enough. Prompt interpretation of changes in recorded potentials makes it possible for the surgeon to accurately identify the step in the operation that caused the change, which is a prerequisite for proper and prompt surgical intervention and thus, the ability to reduce the risk of postoperative neurological deficits!

Correct identification of the step in an operation that entails a risk of complications may make it possible to modify the way such an operation is carried out in the future and to reduce the risk of complications in subsequent operations. In this way, intraoperative neurophysiological monitoring may also contribute to the development of safer operating methods by making it possible to identify which steps in an operation may cause neurologic deficits, and it thereby, naturally, plays an important role in teaching surgical residents and fellows.

When to Inform the Surgeon

It has been debated extensively whether the surgeon should be informed of all changes in the recorded electrical activity that could be regarded as caused by surgical manipulations or only when such changes reach a level that indicate a noticeable risk for permanent neurological deficits. The dilemma is thus: should the information that is gained be used only as a warning (alarm) that implies that if no intervention is made there is a likelihood that the patient will get a permanent postoperative neurological deficit, or should all information about changes in function be conveyed to the surgeon?

If only information that is presumed to indicate a high risk of neurological deficits is given to the surgeon, then it must be known how large a change in the recorded neuroelectric potentials can be permitted without causing any (detectable) permanent damage. So far, this question has largely remained unanswered. The degree of the change, the nature of the change, and the length of time that the adverse effect has persisted are all factors that are likely to affect the outcome, and the effect of these factors on the risk of postoperative neurological deficits is largely unknown. Individual variation in susceptibility to surgical insults to the nervous system and many other factors affect the risk of neurological deficits in mostly unknown ways and degrees. An individual's disposition, the patient's homeostatic condition, and perhaps the effect of anesthesia on the patient are likely to affect the susceptibility to surgically induced injuries. This all means that it is not possible to define general rules about the level of changes in recorded potentials that does not have any (small) likelihood of causing permanent effects, and thus, it is not possible to know what changes are "safe."

If the surgeon is given information about any noticeable change in the recorded potentials that may be related to his/her action, it is not necessary to know how large a change in recorded potentials can be permitted to occur before any action is taken to reverse the change. Such information is in itself important because it tells the surgeon that the functions of specific structures have been affected. The surgeon can use such information in the planning and the decision making of how to proceed with the operation. This means that changes in the recorded potentials that are larger than the (small) normal variations typically seen in these recordings should be reported to the surgeon if there is reasonable certainty that these changes are related to surgical manipulations. In that way, intraoperative neurophysiological monitoring provides information rather than warnings. Some authors find that the best use of intraoperative neurophysiological monitoring is for the purpose of decreasing the risk of neurological deficits.

If the surgeon is made aware of any change in the recorded potentials that is larger than those normally occurring, it can help the surgeon to carry out the operation in an optimal way with as little risk of adverse effect on neural function as possible. Providing such information gives the surgeon the option of altering his or her course of action in a wide range of time. If the change in the recorded potentials is small, it is likely that the surgeon would be able to reverse the effect by a slight change in the surgical approach or by avoiding further manipulation of the neural tissue affected. Alternatively, the surgeon may choose not to alter technique if the surgical manipulations that caused the changes in the recorded neurophysiological potentials are essential to carrying out the operation in the anticipated way. However, even in such a case, the knowledge that the surgical procedure is affecting neural function in a measurable way is valuable to the surgeon, and continuous monitoring of the change allows the surgeon the ability to modify or not modify the procedure because monitoring has identified which step in the operation caused the change in function.

Other authors have expressed that it is desirable to have general rules (alarm criteria) about the size of changes in the recorded potentials that are allowed and that only when the changes reach such levels should the surgeon be informed. However, if information about a change in the recorded potentials is withheld until the change in the recorded electrical potentials have reached such “alarm” levels, it would be difficult for the surgeon to determine which step in the surgical procedure caused the adverse effect, and thus, it would not be possible for the surgeon to intervene appropriately because he or she would not know which step in the procedure had caused the change. In such a situation, the surgeon would not have had the freedom of delaying his or her action to reverse the change because the problem the change signaled had already reached dangerous levels.

When conveying information about early changes in the recorded potentials, it is important that it be made clear to the surgeon that such information represents guidance details, as opposed to a warning, that the surgical manipulations are likely to result in a high risk of serious consequences if appropriate action is not taken promptly by the surgeon. Warnings are justified, if, for instance, there is a sudden large change in the evoked potentials or if the surgeon has disregarded the need to reverse a manipulation that has caused a slow change in the recorded electrical potentials.

Some patients will likely experience neurological deficits when changes in recorded potentials during an operation are below such alarm levels. The more knowledge that is gathered about the effect of mechanical manipulation on nerves, the more it seems apparent that even slight changes in measures of electrical activity (such as the CAP) may be signs of permanent injury. However, studies that relate changes in evoked potentials to morphological changes and changes in postoperative function are still rare. Thus, relatively little is known quantitatively about the degree to which a nerve can be stretched, heated, or deprived of oxygen before a permanent injury results, but there is no doubt that different nerves respond in different ways to injury due to mechanical manipulations or heat. Even less is known about the relationship between changes in sensory and motor evoked potentials and deficits from deprivation of oxygen.

Presenting information about changes in the recorded neuroelectric potentials as soon as they reach a level where they are detectable also has an educational benefit in that it tells the surgeon precisely which steps in an operation might result in neurologic deficit. It is often possible on the basis of such knowledge to modify an operation to avoid similar injuries in future operations.

The surgeon should be informed of the possibility of a surgically induced injury even in cases in which the change (or total disappearance of the recorded potentials) could be caused by equipment or electrode malfunction. Thus, only after assuming that the problem is biological in nature can equipment failure be considered as a possible cause of the change. Some authors have advocated that if sudden large changes occur, technical problems should be ruled out before the surgeon is notified. Other authors are of the opinion that the surgeon must be informed immediately, and then the neurophysiologist can check the equipment. Technical problems are rare, and if the observed change is caused by equipment failure after the surgeon was informed the only loss would be a few minutes of the surgeon’s time. If, on the other hand, the observed change was caused by some major functional change, precious time would have been wasted if the surgeon’s action was delayed by the search of a technical cause.

False Alarms

The question of false-positive and false-negative responses in intraoperative neurophysiological monitoring has been extensively debated. In some of these discussions, a false-positive response meant that the surgeon was alerted to a situation that would not have led to any noticeable risk of neurological deficits if no action had been taken.

Before discussing false-positive and false-negative responses in intraoperative neurophysiological monitoring, the meaning of false-positive and false-negative responses should be clarified. A typical example of a false-positive result of a test for a specific disease occurs when the test showed the presence of a disease while there was, in fact, no disease present. Using the same analogy, a false-negative test would mean that the test failed to show that a certain individual, in fact, had the specific disease. In the clinic or in screening of individuals without symptoms, false-negative results are more serious than false-positive results. False-positive results may lead to an incorrect diagnosis or unnecessary treatment, while false-negative results may have the dire consequence of no treatment being given for an existing disease.

These definitions cannot be transposed directly to the field of intraoperative neurophysiological monitoring. One reason is that the purpose of intraoperative neurophysiological monitoring is not to detect when a certain surgical manipulation will cause a permanent neurological deficit. Instead, the purpose is to provide information that a (noticeable) risk of permanent neurological deficit may occur. In fact, in most cases when intraoperative neurophysiological monitoring shows changes in function that indicate a risk of causing neurological deficits, no permanent deficits occur. There are no serious consequences associated with these kinds of false-positive responses in intraoperative neurophysiological monitoring.

A situation in which the surgeon was mistakenly alerted to a change in the recorded potentials that was afterward shown to be a result of a technical fault or a harmless change in the nervous system rather than being caused by surgical manipulations may be regarded as a true false-positive response.

The occurrences of false-negative results, which mean that a serious risk has occurred without being noticed, indicate a failure in reaching the goal of intraoperative neurophysiological monitoring, and these failures may have serious consequences.

The conventional definition of false-positive and false-negative results can, therefore, not be applied to intraoperative neurophysiological monitoring because the purpose of monitoring is to identify signs that have a certain risk of leading to such deficits if no action is taken, not to identify individuals with neurological deficits.

Nonsurgical Causes of Changes in Recorded Potentials

Alerting the surgeon as soon as a change occurs implies a faint possibility that a change in evoked potentials may be caused by technical problems that affected some part of the equipment that is used or by a loss of contact of one or more of the electrodes that are used. The characteristics of changes caused by technical problems are usually so different from those of changes in the function of some part of the nervous system caused by injury from surgical manipulations that these two phenomena can easily be distinguished by an experienced neurophysiologist. It is possible that a total loss of recorded potentials can be caused by a technical failure, but it could also be caused by a major failure in the part of the nervous system that is being monitored. However, if such an event should occur, it is much better to first assume that the cause is biologic and to promptly alert the surgeon.

Equipment trouble-shooting activities are secondary actions. In general, when something unusual happens it is advisable to alert the surgeon promptly that something serious may have happened instead of beginning to check the equipment and electrodes. It is highly unlikely that a technical failure will occur and cause a change in the recorded potentials that may be confused with a biological cause for the change. The neurophysiologist should explain to the surgeon that a potentially serious event has occurred, and then after alerting the surgeon, check the equipment and the electrodes for malfunction. The surgeon should not wait for the completion of this equipment check. Instead, he/she should immediately begin his/her own investigation to ascertain whether a surgically induced injury has occurred. If it is discovered that the change in the recorded potentials was caused by equipment malfunction, the surgeon can then be notified, and thus, the only loss that the incident would have caused was a few minutes of the surgeon's time. If such an occurrence is regarded as a "false alarm", then the price for tolerating such "false alarms," namely, that the operation may be delayed unnecessarily for a brief time, seems small compared with what could occur if the equipment was checked before alerting the surgeon.

If the cause of the change in the recorded neuroelectric potentials was indeed a result of an injury that was caused by surgical manipulation of neural structures, and appropriate action was not taken immediately by the surgeon, precious time would have been lost. This would occur if the neurophysiologist had assumed that the cause of the change was technical in nature. Not only would the opportunity to identify the cause of the change be missed by taking the time to check the equipment first, but such a delay could also have allowed the change in function to progress, thus increasing the risk of a permanent neurological deficit. The opportunity to properly reverse the cause of the observed change in the recorded neuroelectric potentials may be lost if action is delayed while searching for technical problems.

In accepting this way of performing intraoperative neurophysiological monitoring, it must also be assumed that everything is done that can be done to keep technical failures that may mimic surgically induced changes in the recorded potentials to an absolute minimum. Actually, high-quality equipment very seldomly malfunctions, and if needle electrodes are used in the way described in the following chapters and care is taken when placing the electrodes, incidents of electrode failure will be rare.

There are factors other than surgical manipulations or equipment failure that can cause changes in the waveform of the recorded potentials, for example, changes in the level of anesthesia, a change in the patient's blood pressure, or change in the patient's body temperature. It is, therefore, important that the person who is responsible for the intraoperative neurophysiological monitoring be knowledgeable about how these factors may affect the neuroelectric potentials that are being recorded. The physiologist should maintain consistent and frequent communication with the anesthesiologist to keep informed about any changes in the level of anesthesia and changes in the anesthesia regimen that may affect the electrophysiological parameters that are to be monitored.

How to Evaluate Neurological Deficits

To assess the success in avoiding neurological deficits, it is important that patients are properly examined and tested both pre- and postoperatively so that changes can be verified quantitatively. In some cases, an injury is detectable only by specific neurologic testing, while in other cases, injury causes impaired sensory function that is noticeable by the patient. Other patients may suffer alterations in neural function that are noticeable to the patient as well as to others in everyday situations. It is, therefore, important that careful objective testing and examination of the patient be performed before and after operations to make accurate quantitative assessments of sensory or neurological deficits.

There is no doubt that the degree to which different types of neurological deficits affect individuals varies, but reducing the risk of any measurable or noticeable deficit as much as possible must be the goal of intraoperative neurophysiological monitoring. (See Chap. 19 for further discussion on these matters.)

AIDING THE SURGEON IN THE OPERATION

In addition to reducing the risk of neurological deficits, the use of neurophysiological techniques in the operating room (intraoperative neurophysiology) can provide information and guidance that can help the surgeon carry out the operation and make better decisions about the next step in the operation. In its simplest form, this may consist of identifying the exact anatomical location of a nerve that cannot be identified visually, or it may consist of identifying where in a peripheral nerve a block of transmission has occurred (*14*). In operations to repair peripheral nerves, intraoperative diagnosis of the nature of the injury and its exact location using neurophysiological methods have improved the outcome of such operations.

An example of a more complex role of intraoperative recording is the recording of the abnormal muscle response in patients undergoing microvascular decompression operations to relieve HFS (*15, 16*). This abnormal muscle response disappears when the facial nerve is adequately decompressed (*17*), and by observing this response, it is possible to identify the blood vessel or blood vessels that caused the symptoms of HFS, as well as to ensure that the facial nerve has been adequately decompressed.

Electrophysiological guidance for placement of lesions in the basal ganglia and the thalamus for treatment of movement disorders and pain is absolutely essential for the success of such treatment. More recently, making lesions in these structures has been replaced by electrical DBS, and electrophysiological methods are equally important for guiding the placement of electrodes for DBS (*18, 19*).

There is no doubt that implantation of electrodes for DBS and for stimulation of specific structures in the spinal cord will expand during the coming years. Such treatments are attractive in comparison with pharmacological (drug) treatments in that electrophysiological treatments are more specific and have fewer side effects than drug treatments. While a physician with a license to practice medicine can prescribe many complex medications, procedures such as electrode implantation for DBS require expertise in both surgery and neurophysiology, and intraoperative neurophysiological monitoring must be performed adequately. This means that the need for people with neurophysiological knowledge and operating room experience will be in increasing demand for the foreseeable future.

The future will see the development of many other presently unexplored areas in which intraoperative neurophysiological recordings will become an aid to the surgeon in specific operations, and the use of neurophysiological methods in the operating room will expand as a means to study normal as well as pathological functions of the nervous system.

WORKING IN THE OPERATING ROOM

Intraoperative neurophysiological monitoring should interfere minimally with other activities in the operating room. If monitoring causes more than minimal interference, there is a risk that it will not be requested as often as it should. There is so much activity in modern neurosurgical, otologic, and orthopedic operating rooms that adding activity that consumes time will naturally be met with a negative attitude from all involved and may result in the omission of intraoperative neurophysiological monitoring in certain cases. Careful planning is necessary to ensure that intraoperative neurophysiological monitoring interferes with other forms of monitoring and the use of life-support equipment as little as possible.

How to Reduce the Risk of Mistakes in Intraoperative Neurophysiological Monitoring

The importance of selecting the appropriate modality of neuroelectric potentials for monitoring purposes cannot be overemphasized, and making sure that the structures of the nervous system that are at risk are included in the monitoring is essential. Thus, monitoring SSEP elicited by stimulating the median nerve while operating on the thoracic or lumbar spine may lead to a disaster because it is the thoracic lumbar spinal portion of the somatosensory pathway that is at risk of being injured while only the cervical portion of the somatosensory pathway is being monitored.

Monitoring the wrong side of the patient's nervous system is also a serious mistake. An example of this monitoring error is presenting the sound stimulus to the ear opposite to the side on which the operation is being performed while monitoring ABR. This kind of mistake may occur when earphones are fitted in both ears and selection of which earphone to be used is controlled by the neurophysiologist. A user error may select the wrong earphone to be used. Since the ABR is not fundamentally different when elicited from the opposite side, such a mistake will not be immediately obvious, but it will naturally prevent the detection of any change in the ear or auditory nerve as a result of surgical manipulation. The possible catastrophic consequence of failing to detect any change in the recorded potentials when the auditory nerve is injured by surgical manipulation is obvious.

Generally speaking, if a mistake can be made by the action of the user (neurophysiologist), it will be made, but it may be rare. Mistakes may be tolerated, depending on the consequences and the frequency of their expected occurrence. Mistakes can only be avoided if it is physically impossible to make the mistake. Thus, only by placing an earphone solely in the ear on the operated side can the risk of stimulating the wrong ear be eliminated. If earphones are placed in each ear, the risk of making mistakes can be reduced by clearly marking the right and left earphone and only having properly trained people operate the stimulus equipment. This will reduce the risk of mistakes but not eliminate mistakes.

In a similar way, monitoring the wrong part of the spinal cord may cause serious neurologic deficits since no change in the recorded neuroelectric potentials would be noticed during the operation. When an operation involves the spinal cord distal to the cervical spine and stimulating electrodes are placed in the median nerve as well as in a nerve of the lower limb, the median nerve may mistakenly be stimulated when the intention was to elicit evoked potentials from the lower limb. It is, however, valuable to monitor median nerve SSEP because it is a check that the positioning does not injury the brachial plexus. The considerable difference between the waveform of the upper limb SSEP and that of the lower limb SSEP may make the mistake of watching median nerve SSEP instead of lower limb SSEP during the operation more easily detectable than mistakes made eliciting ABR by stimulating the wrong ear or when eliciting SSEP from the wrong part of the spine.

Reliability of Intraoperative Neurophysiological Monitoring

Like any other new addition to the operating room armamentaria, intraoperative neurophysiological monitoring must be reliable to enjoy routine use. It is not unreasonable to assume that if intraoperative neurophysiological monitoring cannot always be carried out (and consequently, operations are performed without the aid of monitoring), it may be assumed by the surgeon that it is not necessary at all to have such monitoring.

Reliability can best be achieved if only routines that are well thought through and which have been thoroughly tested are used in the operating room. The same methods that have been found to work well over a long time should be used consistently. New routines, or modifications of old routines, should only be introduced in the operating room after thorough consideration and testing. Procedures of intraoperative neurophysiological monitoring should be kept as simple as possible. The KISS (Keep it Simple (and) Stupid or Keep it Simple and Straightforward) principle is applicable to intraoperative neurophysiological monitoring. These matters are discussed in detail in Chaps. 17 and 18.

Electrical Safety and Intraoperative Neurophysiological Monitoring

A final, but not inconsiderable, concern is that intraoperative neurophysiological monitoring should not add risks to the safety, particularly electrical safety, of any operation. Intraoperative neurophysiological monitoring requires the addition of complex electrical equipment to an operating room already crowded with a variety of complex electrical equipment. Electrical safety is naturally of great concern whenever electronic equipment is in direct galvanic contact with patients, but this is particularly true in the operating room, where many pieces of electrical equipment are operated together, often in crowded conditions, and frequently under wet conditions. The equipment and procedures used for intraoperative neurophysiological monitoring must, therefore, be chosen with consideration for the protection of the patient as well as of the personnel in the operating room from electrical hazard. Accidents can best be avoided when those who work in the operating room and who use the electronic equipment are knowledgeable about the function of the equipment and how risks of electrical hazards that are associated with specific equipment may arise. For the neurophysiologist, it is important to have a basic understanding of how electrical hazards may occur and to specifically have an understanding of the basic functions of the various pieces of equipment used in electrophysiological monitoring. The area of greatest concern in maintaining electrical safety for the patient is the placement of stimulating and recording electrodes on the patient. It is particularly important to consider the safety of the patient that is connected to equipment by electrodes placed intracranially for either recording or stimulation (for details, see Chap. 17).

HOW TO EVALUATE THE BENEFITS OF INTRAOPERATIVE NEUROPHYSIOLOGICAL MONITORING

It is the patient that can gain the most from intraoperative neurophysiological monitoring. Many of the severe postoperative neurological deficits that were common before the introduction of intraoperative neurophysiological monitoring are now rare occurrences. It is not only the use of intraoperative neurophysiological monitoring that has enabled these improvements of medical care; better surgical techniques and various technological advancements have led to significant progress as well. There is no doubt that the introduction of microneurosurgery (and more recently, minimally invasive surgery) has made operations that affect the nervous system less brutal than they were 25 years ago, and even the last decade has seen steady improvements in reducing complications (see also Chap. 19).

Assessment of Reduction of Neurological Deficits

It has been difficult to accurately assess the value of intraoperative neurophysiological monitoring with regard to reducing the risk of postoperative neurological deficits. One of the reasons for these difficulties is that it has not been possible to apply a commonly used method, such as double-blind methods, to determine the value of intraoperative neurophysiological monitoring. Surgeons who have experienced the advantages of intraoperative neurophysiological monitoring are reluctant to deprive their patients of the benefits provided by an aid in the operation that they believe can improve the outcome. The use of historical data for comparison of outcomes before and after the introduction of monitoring has been described in a few reports, but such methods are criticized because advancements in surgical techniques other than intraoperative neurophysiological monitoring may have contributed to the observed improvement of outcomes. Even more difficult to evaluate is the increased feeling of security that surgeons note while operating with the aid of intraoperative neurophysiological monitoring.

For the sake of evaluating future benefits from monitoring, it is important that all patients who are monitored intraoperatively be evaluated objectively before and after the operation and that the results obtained during monitoring be well documented. (For more details about evaluation of the benefit from intraoperative monitoring and neurophysiology, see Chap. 19.)

Which Surgeons Benefit Most from Intraoperative Monitoring?

Surgeons at all levels of competence may benefit in one way or another from the use of intraoperative neurophysiological monitoring, but the degree and the kind of benefit depends on the experience of the surgeon in the particular kind of operation being performed. While an extremely experienced surgeon may benefit from monitoring only in unusual situations or for confirming the anatomy, a surgeon with moderate-to-extensive experience may feel more secure and may have additional help in identifying specific neural structures when using monitoring. A surgeon with moderate-to-extensive experience will also benefit from knowing when surgical manipulations have injured neural tissue. A less-experienced surgeon who has performed only a few of a specific type of operations is likely to benefit more extensively from using intraoperative neurophysiological monitoring, and surgeons at this level of experience will learn from intraoperative monitoring and, through that, improve his/her surgical skills.

Even some extremely experienced surgeons declare the benefit from neurophysiological monitoring and appreciate the increased feeling of security when operating with the assistance of monitoring. Many very experienced surgeons are in fact not willing to operate without the use of monitoring.

In fact, most surgeons can benefit from intraoperative neurophysiological monitoring mainly by its aid in reducing the risk of postoperative neurological deficits as well as by its ability to provide the surgeon with a feeling of security from knowing when neural tissue is being adversely manipulated. Most surgeons will appreciate the aid that monitoring can provide in confirming the anatomy when it deviates from normal as a result of tumors, other pathologies, or extreme variations.

RESEARCH OPPORTUNITIES

The operating room offers a wealth of research opportunities. In fact, many important discoveries about the function of the normal nervous system, as well as about the function of the pathological nervous system, have been derived from research activities within the operating room. Neurophysiological recordings are almost the only way to study the pathophysiology of many disorders. Many important discoveries were made by applying neurophysiological methods to work in the operating room, but many discoveries were made before the introduction of intraoperative neurophysiological monitoring (*20, 21*), and many studies were made in connection with intraoperative neurophysiological monitoring (*17, 22, 23*). Some studies have concerned basic research (*24*), other studies have been directly related to the development of better treatment and better surgical methods (*17, 22, 23*), and some studies have served both purposes (*17, 20, 22, 24–29*).

REFERENCES

1. Brown RH and CL Nash (1979) Current status of spinal cord monitoring. Spine 4:466–78.
2. Grundy B (1983) Intraoperative monitoring of sensory evoked potentials. Anesthesiology 58:72–87.
3. Grundy B (1985) Evoked potentials monitoring, in *Monitoring in Anesthesia and Critical Care Medicine*, C Blitt, Editor. Churchill-Livingstone: New York. 345–411.
4. Raudzens PA (1982) Intraoperative monitoring of evoked potentials. Ann. N. Y. Acad. Sci. 388:308–26.
5. Jako G (1965) Facial nerve monitor. Trans. Am. Acad. Ophthalmol. Otolaryngol. 69:340–2.
6. Rand RW and TL Kurze (1965) Facial nerve preservation by posterior fossa transmeatal microdissection in total removal of acoustic tumours. J. Neurol. Neurosurg. Psychiatry 28:311–6.
7. Møller AR and PJ Jannetta (1984) Preservation of facial function during removal of acoustic neuromas: use of monopolar constant voltage stimulation and EMG. J. Neurosurg. 61:757–60.
8. House J and D Brackmann (1985) Facial nerve grading system. Otolaryngol. Head Neck Surg. 93:146–67.
9. Sekhar LN and AR Møller (1986) Operative management of tumors involving the cavernous sinus. J. Neurosurg. 64:879–89.
10. Møller AR (1987) Electrophysiological monitoring of cranial nerves in operations in the skull base, in *Tumors of the Cranial Base: Diagnosis and Treatment*, LN Sekhar and VL Schramm Jr, Editors. Futura Publishing Co: Mt. Kisco, New York. 123–32.

11. Yingling C (1994) Intraoperative monitoring in skull base surgery, in *Neurotology*, RK Jackler and DE Brackmann, Editors. Mosby: St. Louis. 967–1002.
12. Deletis V (1993) Intraoperative monitoring of the functional integrety of the motor pathways, in *Advances in Neurology: Electrical and Magnetic Stimulation of the Brain*, O Devinsky, A Beric and M Dogali, Editors. Raven Press: New York. 201–14.
13. Prass RL and H Lueders (1986) Acoustic (loudspeaker) facial electromyographic monitoring. Part I. Neurosurgery 392–400.
14. Kline DG and DJ Judice (1983) Operative management of selected brachial plexus lesions. J. Neurosurg. 58:631–49.
15. Møller AR and PJ Jannetta (1987) Monitoring facial EMG during microvascular decompression operations for hemifacial spasm. J. Neurosurg. 66:681–5.
16. Haines SJ and F Torres (1991) Intraoperative monitoring of the facial nerve during decompressive surgery for hemifacial spasm. J. Neurosurg. 254–7.
17. Møller AR and PJ Jannetta (1985) Microvascular decompression in hemifacial spasm: intraoperative electrophysiological observations. Neurosurgery 16:612–8.
18. Deletis V and JL Shils (2004) *Neurophysiology in Neurosurgery*. Amsterdam: Academic Press.
19. Shils JL, M Tagliati and RL Alterman (2002) Neurophysiological monitoring during neurosurgery for movement disorders, in *Neurophysiology in Neurosurgery*, V Deletis and JL Shils, Editors. Academic Press: Amsterdam. 405–48.
20. Penfield W and E Boldrey (1937) Somatic motor and sensory representation in the cerebral cortex of man as studied by electrical stimulation. Brain 60:389–443.
21. Ojemann GA, O Creutzfeldt, E Lettich et al (1988) Neuronal activity in human lateral temporal cortex related to short-term verbal memory, naming and reading. Brain 111:1383–403.
22. Lenz FA, JO Dostrovsky, HC Kwan et al (1988) Methods for microstimulation and recording of single neurons and evoked potentials in the human central nervous system. J. Neurosurg. 68:630–4.
23. Lenz FA, HC Kwan, RL Martin et al (1994) Single unit analysis of the human ventral thalamic nuclear group. Tremor-related activity in functionally identified cells. Brain 117:531–43.
24. Lenz FA, JO Dostrovsky, RR Tasker et al (1988) Single-unit analysis of the human ventral thalamic nuclear group: somatosensory responses. J. Neurophysiol. 59:299–316.
25. Lenz FA and NN Byl (1999) Reorganization in the cutaneous core of the human thalamic principal somatic sensory nucleus (Ventral caudal) in patients with dystonia. J. Neurophysiol. 82:3204–12.
26. Ojemann GA (1988) Effect of cortical and subcortical stimulation on human language and verbal memory. Res. Publ. Assoc. Res. Nerv. Ment. Dis. 66:101–15.
27. Ojemann GA (1975) Language and the thalamus: object naming and recall during and after thalamic stimulation. Brain Lang. 2:101–20.
28. Ojemann JG, GA Ojemann and E Lettich (1992) Neuronal activity related to faces and matching in human right nondominant temporal cortex. Brain 115:1–13.
29. Penfield W and T Rasmussen (1950) *The Cerebral Cortex of Man: A Clinical Study of Localization of Function*. New York: Macmillan.

http://www.springer.com/978-1-4419-7435-8

Intraoperative Neurophysiological Monitoring
Møller, A.R.
2011, X, 403 p., Hardcover
ISBN: 978-1-4419-7435-8