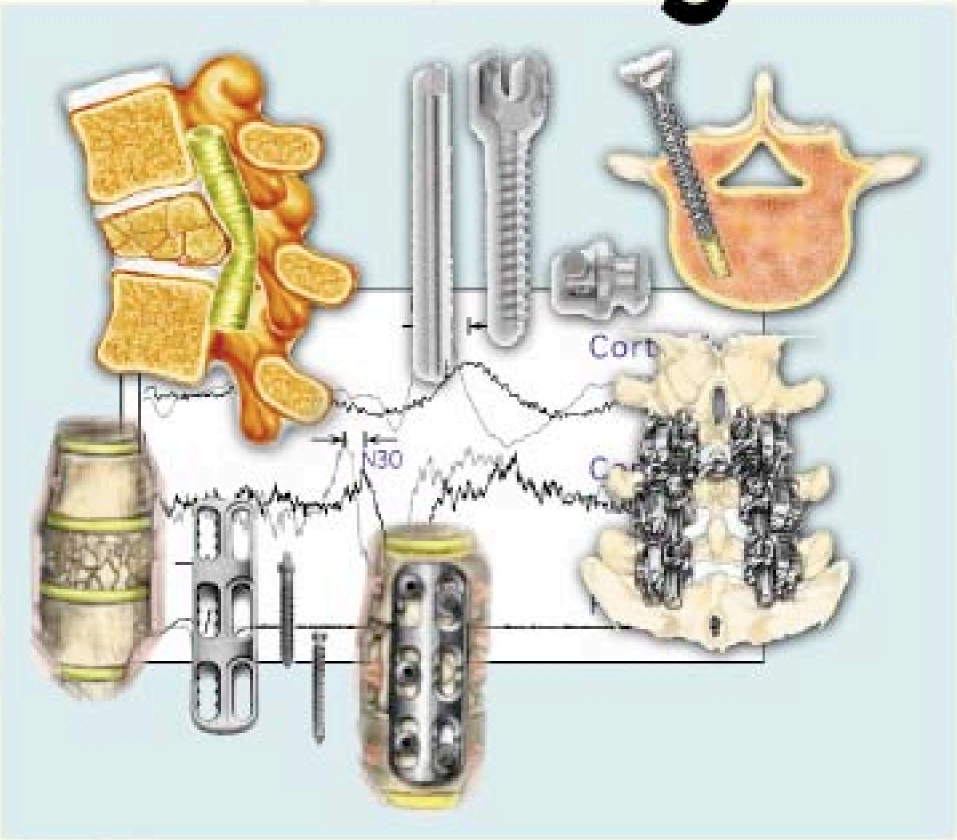
A CONCISE GUIDE TO

Intraoperative Monitoring



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Preface

Intraoperative electrophysiological recordings are gradually becoming part of standard medical practice, mainly because they offer an objective and effective way to assess the functional integrity of the nervous system of patients during the course of orthopedic, neurological, or vascular surgery. Continuous monitoring of bioelectrical activity not only can avert damage of neurological structures that are at risk during certain surgical maneuvers, but also allows identification of specific neuronal structures and landmarks that cannot be easily recognized on anatomical grounds only.

Early applications of intraoperative monitoring were limited to a neuroprotective role. Today, however, monitoring not only decreases the risk for permanent neurological deficits but also provides surgeons with continuous information pertaining to the functional integrity of neuronal structures at risk and allows them to modify their actions accordingly in an effort to achieve optimal results.

Intraoperative monitoring is still not perfect. In fact, results are affected by several factors that may lead to false positive and negative judgments or interpretations. However, until more advanced procedures become available and practical, monitoring will remain a very useful and clinically valid procedure that can improve surgical outcome.

This book, based on our experience with the intraoperative monitoring service at Hermann Hospital and on that of others, introduces the various recording techniques available today, the rationale for their intraoperative use, the basic principles on which they are based, as well as problems typically encountered with their implementation. Specific features of the recorded signals, proper parameter settings for acquisition, and factors that affect the recordings, with emphasis on anesthetic agents and various neuroprotective induced conditions, such as hypothermia and hypotension, are reviewed in detail. Recommendations for procedure implementation, proper interpretation of the recordings, and successful equipment troubleshooting are also given. Finally, each chapter concludes with a series of questions to help the reader review the major points presented in the chapter.

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George Zouridakis, Ph.D., is Associate Professor and Director of the Bioimaging Laboratory in the Department of Neurosurgery of the University of Texas-Houston Medical School. He has served as a founding member of the Intraoperative Monitoring Service at Memorial-Hermann Hospital. Dr. Zouridakis's clinical activities currently focus on functional neurosurgery and brain mapping. His research interests involve the development of techniques for image processing, pattern recognition, automated detection, and modeling of biosignals using nonlinear dynamical analysis and fuzzy decision making. In the area of medical imaging, Dr. Zouridakis has developed a graduate course that he currently teaches at Rice University. Since the early stages of his career, he has received several awards and he is also listed in *Who's Who in America.*

A.C. Papanicolaou, Ph.D., is a member of the American Society of Neurophysiological Monitoring and Professor and Director of the Division of Clinical Neurosciences in the Neurosurgery Department of the University of Texas-Houston Medical School and the Magnetoencephalography Center at the Memorial-Hermann Hospital. During the past 20 years Dr. Papanicolaou has worked and published extensively in the areas of brain electrophysiology, neuropsychology, cognitive neurosciences and functional brain imaging, the fundamentals of which he has presented in a recent textbook. In 1993, he organized and directed the Intraoperative Monitoring Service at Memorial-Hermann Hospital where he still contributes as a member of the pallidotomy team.

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chapter 1

Introduction

1.1 Intraoperative Monitoring

Electrophysiological recordings during orthopedic, neurological, and vascular surgery are gradually becoming part of standard medical practice, mainly because these procedures, unlike other intraoperative techniques such as X-ray and ultrasound imaging which provide information on the anatomical status of a structure, provide information regarding the *functional integrity* of the nervous system of a patient who, typically, is anesthetized and therefore cannot be neurologically examined. The value of these procedures, which are collectively known as *intraoperative monitoring* (IOM), stems from the fact that they are *practical* (no active patient participation is required), *reliable* (normal recordings are known to be very stable over time), and *sensitive* (they can promptly detect small changes in the activity of the nervous system).

Typical recordings include monitoring of the spontaneous electrical activity of the brain, which is recorded on the scalp as the electroencephalogram (EEG), and that of muscles, which can be obtained by placing electrodes in the vicinity of contracting muscles and is referred to as an electromyogram (EMG). However, the most commonly recorded signals in the operating room are *evoked potentials* (EPs), which are the electrophysiological responses of the nervous system to external stimulation.

Early applications of intraoperative monitoring were limited to only a few tests. The original use of somatosensory EPs in the late 1970s was to monitor spinal cord function during Harrington rod instrumentation for scoliosis [16, 51]. At that time, attempts to preserve facial nerve function led to monitoring facial muscle contractions through recordings of EMG activity [14]. Later, after their discovery in humans [27], auditory brainstem responses (ABRs) were among the modalities routinely monitored during surgical operations for acoustic tumors [13, 22] with the intention to preserve hearing and vestibular nerve functions. Currently, additional tests have been developed specifically for intraoperative use, covering a wider range of applications.

1.2 Use

In general, the application of these procedures intraoperatively serves a dual purpose. The first purpose, already mentioned earlier, is to avert damage of neuronal structures that are at risk during certain surgical maneuvers. For instance, as will be described in greater detail in Chapter 8, during surgery for scoliosis (see Section 8.2), monitoring of the spinal cord through EPs can provide early warnings of impending damage due to misplaced instrumentation or to unintended manipulation of the cord, like for example, excessive distraction. Or, during a carotid endarterectomy (see Section 9.5), potentially dangerous decreases in cortical blood perfusion rates can be inferred from EEG and EP recordings and corrected in time.

The second purpose is to identify specific neuronal structures and landmarks that cannot be easily recognized on anatomical grounds only. For example, during surgery for epilepsy, identification of the *central sulcus* which separates the motor and sensory areas of the cerebral cortex can be achieved by delineating the somatosensory area using a simple EP test (see Section 9.7).

1.3 Rationale

Events occurring in the external environment, such as sounds and lights, are detected by the sense organs and information about them is transmitted to the brain in the form of electrical signals through various sensory neural pathways. The arrival of these signals in the brain gives rise to certain patterns of brain activity, provided that these pathways are structurally and functionally intact. Consequently, examination of these patterns of brain activity can provide valuable information regarding the integrity of the neural structures that constitute the pathway.

In general, two consequences of surgical intervention, however infrequent, can compromise the functional integrity of the nervous system and possibly lead to post-operative neurological deficits: *ischemia* and *mechanical injury.* These insults are typically manifested as a change in the morphology, amplitude, or frequency content of the electrophysiological signals being recorded. Continuous measurement of these waveform parameters and comparison with pre-established normative values allows one to assess, on-line, the functional integrity of neuronal structures over time.

Therefore, intraoperative neurophysiological monitoring provides an objective way to *detect* and *quantify,* instant by instant, changes in the functional status of neurological structures early enough, so that actions can be taken to possibly reverse the effects of ischemia, prevent permanent mechanical injury, and restore normal function. And since the information is provided in real time, through monitoring one can also assess the efficacy of a corrective action, e.g., removal of an arterial clamp that had previously resulted in local ischemia (see Figure 9.18). Monitoring can also help the surgeon to assess the effectiveness of surgical intervention, such as, for example, the adequacy of root decompression in the case of a radiculopathy (see Section 8.3).

1.4 Types of Tests

Intraoperative monitoring employs recordings of two main categories of bioelectric signals: spontaneous activity and evoked responses. Examples of the former category are the spontaneous activity of the brain (EEG) (see Section 6.2) and of muscles (EMG) (see Section 6.3). Recordings in the latter category are obtained through external stimulation of a neural pathway. Typical stimuli used in sensory stimulation consist of small electrical shocks, clicking sounds, and flashes of light, which result in the familiar somatosensory, auditory, and visual evoked potentials, respectively. Similarly, electrical or magnetic stimulation of a motor pathway gives rise to the so-called motor evoked potentials.

Evoked responses usually are very small compared to the ongoing activity, thus averaging of a large number of them is necessary to obtain clear response waveforms. Somatosensory and auditory evoked potentials are examples of averaged responses. In certain cases, however, individual stimuli result in large responses, therefore, averaging is not necessary. This is the case, for example, of an electrical stimulus delivered to spinal nerves resulting in high-amplitude responses known as triggered EMG (see Section 7.8).

Depending on the site of stimulation, evoked responses can be recorded from the brain, the spinal cord, a peripheral nerve, or a muscle. Unfortunately, there is no single monitoring procedure that can be used in all circumstances. The type of test to be used and the sites of recording and stimulation are chosen on a case by case basis, depending on what structures are at risk in the context of a particular surgical procedure. And, very often, it is necessary to employ multiple tests simultaneously, in order to maximize the sensitivity of IOM.

1.5 Affecting Factors

In addition to surgical manipulation which, unintentionally, may result in ischemia or mechanical injury, neurophysiological recordings are also affected by other *perisurgical* factors, such as blood pressure, body temperature and, most importantly, the anesthesia regime. Of course, there is always the additional possibility of a technical problem which may result in a drastic change in the recordings. Familiarity with all these factors is necessary for proper interpretation of any activity changes that might be detected during the course of surgery.

Most anesthetic drugs influence neurophysiological signals because of the effects they have on cerebral blood flow, perfusion, and metabolic rate. Hence, collaboration of the monitoring team with the anesthesiologist is critical in developing a proper anesthesia plan suitable for both the surgical *and* the monitoring procedures. An overview of anesthesia management during neurological, orthopedic, and vascular surgery will be given in Section 5.2.

1.6 Interpretation

Besides the above-mentioned factors that affect neurophysiological recordings, there are additional ones related to artifacts. Extraneous biological noise, such as the electrocardiographic (ECG) or muscle activity, electrical interference, like the omnipresent 60 Hz activity, or equipment failure, for instance a faulty stimulating device, will all contribute to the difficulty in correctly interpreting the recordings and the ability of differentiating artifacts from changes due to ischemia or mechanical injury.

In general, ischemia and mechanical insult will result in (1) a decrease in the number of neurons responding to stimulation, and (2) desynchronization of neuronal firing. From an electrophysiological point of view, these changes are detected as a reduction in the amplitude, an increase in the latency, and an overall change in the morphology of a waveform. Although there are no exact values of amplitude and possibly latency changes that absolutely predict neurologic outcome [6], for each test there are recommended values which can be used as a "rule of thumb" for warning the surgical team about a significant change in the recordings.

As will be explained in later chapters, careful observation of the context in which signal changes occur, including surgical maneuvers (tissue retraction, instrumentation placement, etc.) and other perisurgical factors (bolus injection of drugs, decreased blood pressure, etc.), as well as communication with the surgeon and the anesthesiologist, allows one to correctly assess the importance of these changes.

1.7 Usefulness

The merits of intraoperative monitoring have been extensively reported in the literature from different institutions worldwide and for a variety of types of surgery.

For example, several studies have shown the benefits of spinal cord monitoring during surgery for scoliosis [32, 53, 57, 60, 68]. A large multicenter survey found that such monitoring has a *sensitivity* (the true positive out of the total true positive and false negative change detections) of 92% and a *specificity* (the true negative out of the total true negative and false positive change detections) of 98.9%, with an even higher negative predictive value of 99.93% (the true negative out of true negative and false negative change detections), indicating that the test is highly likely to be accurate when no changes are detected [53]. Also, in neurovascular cases EP findings were found to be consistent with the clinical outcome [52] and could be used intraoperatively for early detection of ischemia and for assessing the efficacy of surgical countermeasures [40], thus allowing for overall safer operations [61].

Similarly, intraoperative monitoring of compound nerve action potentials from various cranial nerves has proven to be an invaluable tool in avoiding neurological damage and preserving function of the facial, cochlear, trigeminal, spinal accessory, and oculomotor nerves [30, 47, 62, 75].

Also, auditory brainstem responses (ABRs) have found widespread clinical applications in assessing the integrity of the peripheral auditory structures and brainstem pathways [38] and have made brain retraction, which is required for adequate exposure during many intracranial procedures, a much less common source of morbidity [4].

However, beyond the main objective of early detection of possible neurological complications to allow for their timely correction, intraoperative monitoring has other advantages. Continuous feedback regarding neurological function provides the medical team with additional reassurance and allows the surgeons to carry out the operation in an optimal way [47] attempting, for instance, more aggressive maneuvers that otherwise they would not risk attempting [53]. Also, certain high-risk patients previously regarded as inoperable can now be considered as candidates for surgery.

1.8 Cost Effectiveness

It would seem obvious that if intraoperative monitoring can decrease the risk of permanent postoperative neurological deficit, or the time it takes to perform an operation, then the cost related to the service would be justified. In economic terms, however, even when the cost of suffering is not included, it has been estimated that the use of intraoperative monitoring in certain cases is clinically cost-effective as the risk of postoperative complications approaches 1% [53].

Nevertheless, it is important to keep the surgical cost within reasonable limits, by carefully selecting to perform monitoring in patients who would *likely* benefit from it as opposed to performing it indiscriminately just because it is available.

1.9 Personnel

Guidelines for proper intraoperative monitoring have been set forth by the American Electroencephalographic Society [6] and include recommendations for equipment, personnel, and documentation. Selection of proper personnel to perform intraoperative monitoring is critical. It has been found that experience of the monitoring team is the primary predictor of the rate of neurological deficits. Specifically, teams with the least experience had significantly higher rates of neurological deficits (twice as high) compared to the most experienced teams [53] .

Typically, one person (a clinical neurophysiologist) is responsible for several operating rooms, while a technologist is available in each room to place electrodes, setup equipment, and monitor the case during the less critical phases of an operation. This is similar to how anesthesia teams are organized in most institutions.

All personnel involved with monitoring should be able to interpret the recordings and communicate the findings to the surgeons. Given that the degree of familiarity of the surgeons with neurophysiological tests varies, communication should be in a way that the surgeons find useful for their purposes. This implies that at least the person responsible for monitoring, in addition to being able to troubleshoot and solve problems with equipment, should have a strong background in clinical neurophysiology and anatomy, as well as, knowledge about the specific surgical operation being performed.

1.10 Equipment

The choice of equipment for intraoperative monitoring is very important. A typical system consists of a portable, self-contained, computer-controlled unit that includes all the components and has the capacity to perform all the operations essential to the task: recording, stimulation, display, signal processing, and data storage.

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 auditory and somatosensory evoked responses, to meet the needs of specific operations. However, it should also be easy to use, flexible, and should allow modifications in the recording protocol and display parameters, if necessary, thus permitting fast interpretation of the results.

1.11 Organization of the Book

This book provides an overview of the techniques available for intraoperative use and their application to specific surgical procedures. Chapter 2 provides an introduction to the origin of the electrophysiological signals recorded, and a description of their basic features. Chapter 3 gives a brief review on basic concepts in electricity and the technical characteristics of the recording equipment, while Chapter 4 summarizes the characteristics of the recorded signals and the processing they undergo before they can be interpreted. A short description of the most commonly used anesthetic agents and their effects on electrophysiological signals is given in Chapter 5. Chapter 6 and Chapter 7 describe the most typical tests employed during intraoperative monitoring, and give specific examples of recorded activity. Chapter 8 and Chapter 9 summarize the most common types of spinal and cranial surgery, respectively, as well as the tests to employ for appropriate IOM of the structures at risks. Chapter 10 is dedicated to equipment troubleshooting and the development of intervention strategies. Chapter 11 concludes the book with some final remarks on the usefulness, clinical validity, and cost-effectiveness of IOM.

1.12 Review Questions

1. Define intraoperative monitoring (IOM).
2. What are the most common types of electrophysiological signals recorded intraoperatively?
3. What is the purpose of IOM?
4. On what principles is IOM based?
5. Name the two primary risks to the nervous system associated with surgery.
6. What kind of changes are observed in physiological recordings after an ischemic attack of, or mechanical insult to, neuronal structures?

7. Name the various body structures from which evoked responses can be recorded.
8. What are the factors affecting neurophysiological recordings?
9. What kind of noise affects neurophysiological recordings?
10. What kind of benefits does IOM offer?
11. What is the approximate percentage of postoperative complications in spine surgery?
12. Does experience of the IOM personnel affect the rate of postoperative neurological deficits?
13. What is the most common structure of an IOM team?
14. What responsibilities/abilities should personnel involved with IOM have?
15. Name the main parts of an IOM recording system.