

Emerging Subspecialties in Neurology: Neurophysiologic intraoperative monitoring

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In the last 30 years, neurophysiologic intraoperative monitoring (NIOM), also referred to as surgical or operative neurophysiology, has evolved from a part-time preoccupation of a few neurologists to a subspecialty in neurology with dynamic career opportunities. NIOM uses a variety of neurophysiologic signals to warn surgeons and anesthesiologists when the nervous system is at risk of injury during a surgical procedure. Several studies have shown that these warnings often lead to modification of the surgery and consequent reduction in surgical morbidity.¹⁻³

HISTORY The use of intraoperative neurophysiologic techniques to aid surgery can be traced to Wilder Penfield and Herbert Jasper's use of electrocorticography for resection of epileptogenic cortex in the 1930s.⁴ However, it was not until the 1970s that neurophysiologic techniques began to be used during surgeries to reduce the risk of injury to the nervous system.⁵ During the early years, NIOM equipment was "homemade" by neurophysiologists, who served the function of not only interpreting physician but also biomedical engineer and technologist.

By the 1980s and 1990s, research documented the clear utility of somatosensory and brainstem auditory evoked potentials (SEP, BAEP), EEG, and EMG in reducing morbidity of many types of surgeries.^{1,6} Commercial NIOM equipment became available, and academic hospitals started offering NIOM services. Technologists became available with specialized training and certification in NIOM through the American Board of Registration of Electroencephalographic and Evoked Potential Technologists. The technologists were able to help set up the monitoring and run the NIOM equipment.

Over the last decade, motor evoked potentials (MEP) monitoring has become available, has been shown to be safe, and has been shown to reduce morbidity in various types of procedures.⁷⁻⁹ Advances in information technology have improved the NIOM expert's access to data from outside the operating

suite in some situations.¹⁰ Now not only academic but also many community hospitals are able to offer NIOM services.

PRACTICE OPPORTUNITIES The growth of NIOM has created many types of practice opportunities for neurologists with expertise in NIOM. The traditional model has been for neurologists with expertise in central or peripheral clinical neurophysiology employed by university hospitals to perform NIOM. The neurologist is typically part of a team which includes technologists and possibly other personnel involved with monitoring. In addition to NIOM, these neurologists are frequently involved with EEG, evoked potentials, and EMG interpretation.

While an academic practice remains popular, appropriately trained neurologists in private practice can also perform NIOM for surgeries done in hospitals in which they have privileges. The technologists may be employees of the hospital or contract workers. Neurologists in this type of practice are involved with other clinical neurology activities when not performing NIOM.

A third type of opportunity exists with private companies that perform NIOM at several hospitals. These companies employ both the neurologist and technologist. The neurologist is usually interpreting the data from a remote location and does not have other clinical responsibilities. Appropriate licensure and privileges should be obtained in the state and hospital in which the NIOM is being performed. The many types of practice opportunities available for NIOM have exposed a critical shortage of neurologists with expertise in NIOM.

TRAINING AND EDUCATIONAL OPPORTUNITIES Until about 10 years ago, few neurology fellowship programs offered subspecialty training in NIOM. Those individuals who wanted to practice NIOM learned from mentors outside of a formal

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Table Fellowships offering varying lengths of NIOM training in the United States

| Institution ^a | Location | Name of program | ACGME accredited | No. of fellows | Duration of program, y ^b |
|---|-------------------|---------------------------------|------------------|----------------|-------------------------------------|
| Columbia University | New York, NY | CNP | Yes | 4-6 | 1-2 |
| Cleveland Clinic | Cleveland, OH | NIOM | No | 1 | 1 |
| Duke University Medical Center | Durham, NC | CNP/NIOM | Yes | 2 | 1 |
| Jefferson University Hospital | Philadelphia, PA | CNP/epilepsy ^c | Yes | 3 | 1-2 |
| Johns Hopkins University | Baltimore, MD | CNP/epilepsy ^c /NIOM | Yes | 1 | 1-2 |
| Loyola University | Chicago, IL | CNP/epilepsy ^c | Yes | 2 | 1 |
| Massachusetts General Hospital | Boston, MA | CNP/NIOM | Yes | 5 | 2 |
| Mayo Clinic | Rochester, MN | CNP | Yes | 5 | 1 |
| Medical University of South Carolina | Charleston, SC | CNP | Yes | 2 | 1 |
| Stanford University School of Medicine | Stanford, CA | CNP/NIOM | Yes | 1 | 1 |
| SUNY Downstate Medical Center | Brooklyn, NY | CNP | Yes | 3 | 1 |
| University of California, Los Angeles | Los Angeles, CA | CNP | Yes | 7 | 1-2 |
| University of Illinois Medical Center | Chicago, IL | CNP | Yes | 2 | 1 |
| University of North Carolina at Chapel Hill | Chapel Hill, NC | CNP/epilepsy ^c | Yes | 1 | 1-2 |
| University of Southern California | Los Angeles, CA | CNP/NIOM | Yes | 3 | 1 |
| University of Texas Southwestern Medical Center | Dallas, TX | CNP/NMM/epilepsy ^c | Yes | 5 | 1-2 |
| Vanderbilt University Medical Center | Nashville, TN | CNP | Yes | 8 | 1 |
| Virginia Commonwealth University Health System | Richmond, VA | CNP | Yes | 3 | 1 |
| Wake Forest University Baptist Medical Center | Winston-Salem, NC | CNP | Yes | 4 | 1 |
| Weill-Cornell Medical Center | New York, NY | CNP | Yes | 1 | 2 |

Abbreviations: ACGME = Accreditation Council for Graduate Medical Education; CNP = clinical neurophysiology; NIOM = neurophysiologic intraoperative monitoring; NMM = neuromuscular medicine.

^a The range of exposure to NIOM ranges from elective time to a dedicated year of training (see text for details).

^b ACGME accredits only 1 year of CNP training; additional years are usually not ACGME accredited.

^c Epilepsy fellowships are not currently being accredited by the ACGME.

training program. Often this training occurred after the termination of a formal fellowship. In part due to the increasing need, over the last decade many fellowships have started including NIOM training. Most such training programs are clinical neurophysiology (CNP), epilepsy, EEG, EMG, or neuromuscular medicine fellowships that offer electives in NIOM to those individuals who are interested.

NIOM is one of 4 tracks (others include EEG, EMG, and sleep medicine) of a CNP fellowship recognized by the Accreditation Council for Graduate Medical Education (ACGME).¹¹ All CNP programs must offer training in at least 2 tracks (personal communication between MRN and ACGME). Fellowships offering varying lengths of NIOM training in the United States are listed in the table. Prospective trainees are encouraged to talk with program directors about the extent of training offered in the various programs listed in the table.

In addition to fellowships, several professional societies provide courses in NIOM. The American Academy of Neurology, the American Clinical Neu-

rophysiology Society, and American Association of Neuromuscular and Electrodiagnostic Medicine offer courses ranging from a few hours to 2 days (see society Web sites). Other societies provide education to technologists and other providers. The last few years have also seen an increase in NIOM publications. In the last few years, several textbooks on NIOM have been published.^{12,13}

Along with training and educational opportunities, NIOM certifying examinations are also available. The American Board of Clinical Neurophysiology (ABCN; www.abcn.org) offers a dedicated NIOM examination, whereas the American Board of Psychiatry and Neurology Subspecialty in Clinical Neurophysiology (www.abpn.com/cnp.htm) examination includes questions on NIOM. Board certification is often required by hospitals before privileges are afforded.

RESEARCH An advantage of an emerging specialty is the enormous research potential. Though the utility of some types of NIOM has been clearly established (such as SEP in scoliosis surgery, BAEP in

microvascular decompression surgery, and MEP in spinal cord surgery), many monitoring modalities require validation of their utility.^{1,6,9} There is a paucity of outcomes research in NIOM. Surgical procedures become progressively more complicated, and innovative monitoring techniques are needed to minimize the risk of injury to the nervous system. NIOM research is a lucrative area for career development.

NIOM research also presents unique challenges. Controlled studies are ethically and medicolegally difficult to perform. It is impossible to control for surgical technique and skill. Despite these limitations, well-designed studies can provide useful data.

DISCUSSION NIOM is an exciting emerging subspecialty of neurology. There are many practice opportunities. The number of fellowships offering NIOM training is increasing. Research opportunities are plentiful and offer a path for career development. Hospital administrators, department chairs, division chiefs, and senior partners appreciate the need for neurologists with expertise in NIOM.

DISCLOSURE

Dr. Husain has received speaker honoraria from UCB, Pfizer Inc, and Jazz Pharmaceuticals; serves on the editorial board of the *Journal of Clinical Neurophysiology*; receives publishing royalties for *A Practical Approach to Neurophysiologic Intraoperative Monitoring* (Demos Medical Publishing, 2008); serves on speakers' bureaus for UCB and Jazz Pharmaceuticals; performs NIOM in his practice at Duke University Medical Center; has received research support from UCB, Pfizer Inc, the NIH, and the American Epilepsy Society; and has served as an expert witness in a medico-legal case. Dr. Emerson serves on the editorial board of the *Journal of Clinical Neurophysiology*; has filed patents re: Dynamic adjustable spatial granularity for EEG display and systems and methods for measuring brain activity; serves as a consultant for Persyst Development Corporation; performs intraoperative monitoring (60%–70% clinical effort); receives research support from Blackrock Microsystems, NYSCIRB, Columbia University, and Epilepsy Therapy Project; and owns stock in Amgen, Johnson & Johnson, Forest Laboratories, Inc., Eli Lilly and Company, and NeuroPace, Inc. Dr. Nuwer serves on a scientific advisory board for Corticare; serves on editorial advisory boards for *Clinical Neurophysiology*, *Journal of Clinical Neurophysiology*, *Practical Neurology*, and *Medical Economics*; serves as a consultant for Mattel; serves as Local Medical Director for SleepMed-Digitrace; receives research support from Bristol-Myers Squibb; holds stock in Corticare; and has provided depositions and expert testimony in medico-legal cases.

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