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# History and Evolution of Facial Nerve Monitoring

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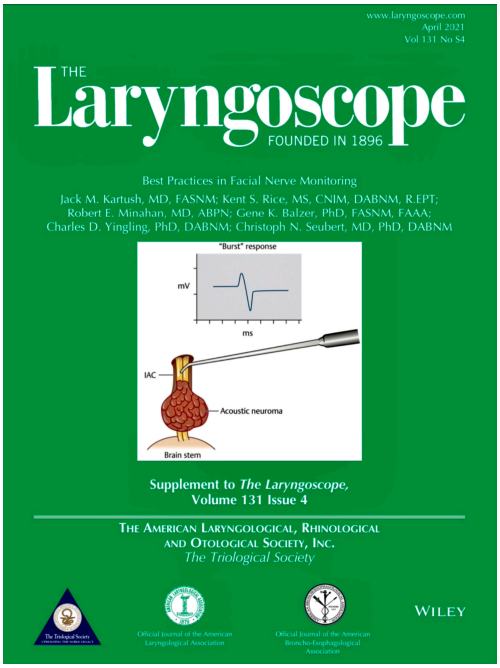


***Facial Nerve Monitoring: Methods and Devices***

Monitoring the facial nerve represents one of the first known attempts at intraoperative neuromonitoring. Facial nerve monitoring (FNM) was first reported in 1898 by Fedor Krause (published as an English translation in 1912).[1] Dr. Krause was an esteemed German neurosurgeon who also performed otologic surgery, including mastoidectomy. He reported on galvanic stimulation and visual facial muscle observation during a cochlear nerve section for tinnitus. In the 1940s, Herbert Olivecrona attempted to preserve the facial nerve during acoustic neuroma (vestibular schwannoma) surgery via

retrosigmoid craniotomy. Like Krause, he used a stimulator while a nurse watched for visible facial movement.[2]

Despite these pioneering attempts at nerve monitoring, there was little interest in FNM during the first half of the 20th century because of the exceedingly high morbidity and mortality of acoustic tumor surgery. Consequently, the incidence of postoperative facial paralysis was nearly 100%. It was considered an expected complication and a "small price to pay" for having the tumor removed. However, improvements in anesthesia and hemostasis gradually began to lower the risks of surgery. In the 1960s, otologist William House's introduction of the operating microscope and alternative surgical approaches to retrosigmoid craniotomy (translabyrinthine and middle cranial fossa) dramatically improved the visibility of all structures within the cerebellopontine angle (CPA), including the facial nerve. This also led to the first team approaches to acoustic tumor surgery that included both a neurosurgeon and an otologist.

With reduced morbidity, there was a renewed interest in facial nerve preservation for acoustic neuroma surgery. Despite the still high risk of paralysis, however, FNM was not resurrected for use during acoustic tumor surgery but instead by general otolaryngologists during parotid and ear surgery. From a practical viewpoint, monitoring during parotidectomy was a simpler affair because the facial muscles could easily be prepped into the surgical field, with responses to electrical stimulation readily visible to the surgeon.

In contrast, during otologic surgery of the middle ear and mastoid, the surgeon could not visualize the face while working through the operating microscope. Instead, the scrub nurse was sometimes instructed to place his/her hand on the sterile drapes covering the patient's face. If the nerve was injured during drilling (or even hammer and chiseling) of the mastoid bone, the nurse might palpate a sudden facial muscle

twitch and could alert the surgeon. Unfortunately, any gross twitch that the nurse could palpate through the drapes typically meant the nerve was severely injured or completely transected.

Advances were made in the 1960s by three otolaryngologists, Richard Parsons,[3] Geza Jako,[4] and Jerome Hilger,[5] who independently reported on dedicated monitors for use during otologic and parotid surgery. Otolaryngologists also benefitted from these devices as a means to test patients with Bell's palsy in the office setting. Jako's method was of interest because rather than relying on visual inspection, it used a mechanical transducer placed on the patient's cheek to assess the response. Hilger subsequently also developed a mechanical transducer that was later improved by Herbert Silverstein in 1985 (WR Electronics, Maplewood, MN). Thus, for decades in the latter half of the 20th century, both the technical and interpretive components of FNM were performed wholly by the surgeon.

In 1979, neurosurgeon Tomas Delgado and his colleagues reported on the use of electromyographic monitoring using adherent surface electrodes during acoustic neuroma surgery.[6] Delgado noted that, "Initially, the presence of an experienced electromyographer in our operating room was necessary; later, with increased familiarity with equipment, the operative team managed alone."

In 1980, Jack Kartush, David Lilly, and Malcolm Graham modified an auditory brainstem recording device (Amplaid, Milan, Italy) to allow electric facial nerve stimulation and EMG recording with subdermal needle electrodes. The normal auditory brainstem recording acoustic signal, calibrated in decibels, required conversion to constant current electricity for facial nerve stimulation. Audiologists were brought into the operating room to set up the complex equipment array and verbally report to the surgeon any time they observed an EMG response on the oscilloscope. Of interest, this led many other audiologists to

enter this new field, thereby expanding their scope of practice.

Neurologists have long performed electromyography by observing not just the visual representation on an oscilloscope but also the acoustic representation when displayed through a loudspeaker. In 1982, Sugita and Kobayashi added the benefit of acoustically displaying the facial EMG response to directly alert the surgeon rather than relying on another individual to constantly gaze at the oscilloscope[7] by using accelerometers to detect facial movement. However, when others began using a loudspeaker with EMG recordings, they encountered loud, disruptive artifacts when electrocautery was used that often startled the surgeon. Consequently, it became essential to have an assistant constantly available to turn down the loudspeaker volume any time cautery was about to be used.

In 1983, Kartush and Richard Prass engaged Nicolet Biomedical Company (Madison, WI) in developing a dedicated constant-current facial nerve monitor with EMG recording displayed visually and acoustically to allow direct, real-time feedback to the surgeon. The device was designed to reduce complexity and obviate the need to "boot up" a generic computer and related software applications. "Intelligent" features were designed such as electrocautery artifact suppression and alarms to warn the surgeon of disconnected electrodes or high impedances. An electronic gate was implemented to transiently silence the stimulus artifact to prevent the surgeon from confusing the stimulus sound with the response sound. In addition, the raw EMG was also converted to an audible tone to highlight the response in the noisy operating room environment. The response tones had different pitches that allowed the surgeon to identify from which EMG channel (ocularis or oris) the response originated. The response tones were programmed to correlate their volume to the amplitude of the EMG response. To test the design, Nicolet engaged the departments of

otolaryngology at the Massachusetts Eye and Ear Infirmary and Stanford University. This device became known as the Nerve Integrity Monitor, or NIM. Prass and Kartush also developed dedicated monopolar and bipolar nerve stimulators optimized for microsurgery. The technology was purchased by Xomed (Jacksonville, FL), which was itself later aquired by Medtronic (Minneapolis, MN).

In 1984, Aage Møller designed a constant-voltage facial nerve stimulator with an acoustic response display (Grass Corp., Quincy, MA). Unfortunately, the device was quickly removed from the market due to liability concerns. In 1992, Michael Gleeson, Tony Strong, and Christopher Hovey developed the Neurosign monitor—a facial nerve stimulator with a loudspeaker and LED lights instead of an oscilloscope to provide a simplified representation of the response's amplitude (Magstim, Carmarthenshire, UK). The absence of an oscilloscope, however, prevented users from assessing EMG responses or artifacts.

EMG recording has become the most commonly used method of monitoring because using subdermal needle electrodes versus surface electrodes or a motion detector increases the sensitivity of the results obtained.[8] This is especially true for intracranial surgery where maximum sensitivity is required to detect trains of low-amplitude neurotonic responses. Recording electrode placement is also important in optimizing EMG recording. Rampp et al.[9] compared a wide inter-electrode distance (i.e., "referential") as recommended by Møller to the close "bipolar" pair recommended by Kartush. Wide inter-electrode recording was much more susceptible to artifacts and frequently missed detecting critical neurotonic A-train activity associated with nerve trauma. Consequently, close bipolar pair recording with subdermal electrodes has become the norm.

Numerous other dedicated devices have been designed since but as the monitoring field has expanded to include multimodality monitoring for brain, spine, and vascular

procedures, most of these latter-day products have been designed with an extraordinary number of features to accommodate many different surgical procedures. However, the inherent complexity that a feature-rich set-up engenders typically mandates the services of a trained technologist or neurophysiologist.

***Adoption of FNM into Clinical Practice***

*"All great truths begin as blasphemies."*

*George Bernard Shaw, Annajanska, 1919*

New ideas in medicine and surgery tend to go through a Schopenhauer-like process: First, ridiculed. Second, violently opposed. Third, acknowledged and accepted as being self-evident.

Consider the invention of electrocautery. Despite the risk of death from intraoperative hemorrhage, the use of electrosurgery "…was considered a stain on the long-standing traditions of the medical profession until relatively recently. Surgeons who pioneered use of this new technology and developed the instruments were chastised as charlatans."[10]

Similarly, despite difficulties in differentiating tumor from surrounding nerves and brain, there was reluctance to use the operating microscope, developed in 1921 by Swedish otolaryngologists Nylén and Holmgren, for middle ear and mastoid surgery.[11] The microscope was not used in neurosurgery until almost 40 years later, after neurosurgeon Theodore Kurze watched a film of otologist William House use one to perform stapes surgery.[12]

These two examples demonstrating the reluctance of physicians to accept new technology are particularly apropos because the operating microscope eventually became one of the pillars of modern CPA surgery. Advances in anesthesia, hemostasis, and surgical visibility were the other pillars that reduced morbidity

and mortality to the point that surgeons could turn their attention to facial nerve preservation.

Even with these advances, the risk of facial paralysis after acoustic tumor surgery was extremely high. Following the pioneering of FNM by Krause in 1898, it was not until 1949 that monitoring was transiently tried and abandoned again by Givré and Olivecrona in Sweden.[2]

The 1960s, however, brought a sudden renewed interest in monitoring as otolaryngologists Hilger, Parsons, and Jako introduced their aforementioned devices intended primarily for parotid and mastoid surgery. Nonetheless, it took two more decades before otologists and neurosurgeons were willing to try monitoring during their operations, which had a much higher risk of facial nerve injury than did parotid surgery. In fact, even in the 1980s, the incidence of facial palsy was so high that many surgeons reported on "anatomic facial nerve preservation" intraoperatively instead of postoperative facial function. It became evident that nerves that looked intact at the end of tumor dissection were often significantly injured by direct, indirect, or thermal (electrocautery) trauma.

Neurosurgeons and otologists disparaged the early attempts at FNM as a "gimmick." One editorial stated, "The novice surgeon should not eagerly attack the posterior fossa just because the patient is being monitored. This author believes a false sense of security may arise when the bells, beeps, and whistles alone are expected to keep the surgeon out of trouble."[13] Certainly, FNM is no substitute for skill or experience but, ironically, years later, many department chairs consider FNM a crucial adjunct for their novices. Bruce Gantz, chair of otolaryngology at the University of Iowa, stated that FNM had become an "imperative in a training environment with residents and fellows."[14] In particular, when used during acoustic tumor surgery, a novice surgeon's technical skills accrue rapidly because they receive real-time feedback if their surgical

manipulations create stretch-induced A-train potentials.

By the mid-1980s, however, a tipping point was reached. Suddenly, there was a plethora of centers reporting on their use of FNM for acoustic tumor operations, all with superior results.[15–19] The efficacy of monitoring became so apparent in high-risk cases such as acoustic tumors that for many surgeons, it became unthinkable to operate without it. In 1988, after using FNM for two years at the Mayo Clinic, Stephen Harner stated, "I don't think I could convince anybody at our institution with experience to give up monitoring under any circumstances."[20] Thus, within a short period, those who were once skeptical believed not only was a controlled, prospective, randomized study not needed but also that it likely would be unethical to withhold monitoring.

Following a 1991 presentation summarizing the benefits of FNM by Kartush to the National Institutes of Health (NIH), the NIH published a national "Consensus Statement on Acoustic Neuroma" recommending that FNM be used routinely. This led to FNM becoming a de facto standard of care in the United States during acoustic tumor surgery.[21] In a recent review of the world literature on FNM for CPA surgery, Acioly et al.[22] concluded, "Intraoperative neuromonitoring has been established as one of the methods by which modern neurosurgery can improve surgical results while reducing morbidity." FNM has joined the other pillars that enhance the safety and efficacy of CPA surgery. The skepticism of FNM's efficacy has faded. Austin Bradford Hill, whose "considerations" for identifying cause-effect relations have often been mistakenly taken as "criteria," wrote in his landmark article[23]:

> *""All scientific work is incomplete—whether it be observational or experimental. All scientific work is liable to be upset or modified by advancing knowledge. That does not confer upon us a freedom to ignore the knowledge we*

*already have, or to postpone the action that it appears to demand at a given time."*

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| lary29459-sup-0001-Online_Supplement_1.docx Word 2007 document , 32.9 KB | **Appendix S1. History and Evolution of Facial Nerve Monitoring** |
| lary29459-sup-0002-Online_Supplement_2.docx Word 2007 document , 17.1 KB | **Appendix S2. Development of Standards for Monitoring in Anesthesia—a Model for Facial Nerve Monitoring?** |
| lary29459-sup-0001-Online_Supplement_3.zip Zip archive, 333.8 MB | **Appendix S3.**<br>**1 - Facial Nerve Monitoring Protocol Checklist 2021 pdf**<br>**2 - IOM electrode montage – color coding pdf**<br>**3 - Video: Placement of blue "eye" recording electrodes just above the brow.**<br>**4 - Video: Placement of red "mouth" recording electrodes along the nasolabial groove.**<br>**5 - Video: Placement of green ground and white anode electrode. The anode represents the return of the stimulus current.**<br>**6 - Video: Final electrode positions secured with clear adhesive tape. These electrical wires will be led off the table to be connected into the headbox. Electrode wires should be kept distant from electrocautery cables in order to reduce artifact as well as the risk of burn injuries.**<br>**7 - Video: Proper color-coded connection of recording electrodes into the headbox. A black-colored sterile cable is used to routinely attach the stimulator to the headbox. The stimulus can be delivered using dedicated monopolar or bipolar probes, or Kartush Stimulating Instruments that allow simultaneous surgical dissection with monopolar stimulation.**<br>**8 - Video: Placement of all electrodes is demonstrated using standardized color-coding to minimize errors.**<br>**9 - Video: Prior to sterile draping of the patient, a "Tap test" is performed to confirm that there are auditory and visual responses elicited by tapping adjacent to the electrodes. Note that this is an artifact, not a true EMG response which can be elicited even when muscle relaxants are present. Therefore, while this test provides critical information, it is not by itself sufficient to demonstrate a fully functioning monitoring set up.**<br>**A - Video: A NIM monitor is used to demonstrate proper pre-check assessments of output volume and electrode impedance.**<br>**B - Video: A novel method to confirm both stimulus and recording functionality is demonstrated by stimulating the facial nerve transcutaneously prior to sterile draping.**<br>**C - Video: A variety of NIM response tones are demonstrated including responses to electric stimulation and trauma: electrically triggered responses, bursts and trains.**<br>**D - Video: Obtaining an early baseline EMG response to electrical stimulation is critical to exclude neuromuscular blockade or temporary paralysis of the facial nerve by local anesthetics.**<br>**E - Video: The response to stimulus evoked facial nerve responses are demonstrated during acoustic tumor resection.**<br>**F - Video: An increased EMG baseline is demonstrated when the depth of anesthesia becomes too light.**<br>**G - Video: EMG train of responses is demonstrated following stretching of the facial nerve. Note that interpretation of EMG trains can only be properly performed when the interpreting professional is aware of the ongoing real-time surgical events.**<br>**H - Video: Proper electrode removal is critical to minimize post-monitoring ecchymoses and trauma to the eye. The eyelids must remain taped shut until the electrodes are off the field.** |