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Chapter 16

Intraoperative Neurophysiology (ION) in Neurosurgery

Vedran Deletis

Introduction

Methodologies of ION

Methodologies for Monitoring the Functional Integrity of the Motor Pathways

Motor Evoked Potentials (MEPs) - Mapping of the Corticospinal tract

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Introduction

As a rule in any scientific discipline, especially in clinical neuroscience, a reliable and simple methodology is the ultimate goal. The same rule can be implemented in the field of Intraoperative Neurophysiology (ION), a sub discipline in Clinical Neurophysiology.

At the very beginning of its development, the original idea for ION was to evaluate online the functional integrity of the nervous system intraoperatively. But the practicality of this idea and its realization faced many problems, which resulted in the neurosurgeons' lack of confidence that ION could help them reduce neurosurgical morbidity. Eventually, a development in neuroanasthesia and new reliable and nervous structures specific methods in monitoring different parts and tracts of the nervous system slowly contributed to the confidence gained in using ION as an every day practice.

In this chapter we will take a non conventional approach to the present achievements and possibilities of ION as it continuous to prevent and document intraoperatively induced injuries to the nervous system. In addition to these achievements, ION now serves as an excellent education tool for the young neurosurgeon.

Methodologies for Monitoring the Functional Integrity of the Motor Pathways

These methodologies are represented in Figure 1 and they are: a) the monitoring of fast conducting neurons of the corticospinal tract (CT) in the form of D and I waves by means of epidural electrodes and b) monitoring of muscle motor evoked potentials (mMEPs) from the limb muscles. Both methods required the use of transcranial electrical stimulation (TES).

One method can substitute the other except in monitoring for surgeries for intramedullary spinal cord tumors in which it is essential to use both methods (Kothbauer et al., 1998). An other example in using a monitoring combination of MEPs with somatosensory evoked potentials (SEP) is presented in Figure. 2. This is an important part of the ION methodology, specifically in this pathology because the disappearance of mMEPs can intraoperatively predict the motor outcome and distinguish between permanent versus transient motor deficits. Furthermore, even in cases when mMEPs disappear, the presence of D wave can encourage the surgeon to continue operating while postoperatively the patient will en up only with transient motor deficits. (Figure 3).

In supratentorial surgeries, using both methods gives us the same predictable results as those in intramedullary spinal cord tumor surgeries, i.e., they can predict early postoperative motor status that distinguishes between permanent and transient motor deficits (Figure. 4). Today, most of the neurosurgical centers use only mMEPs in supratentorial surgeries in combination with SEPs. How useful is the combination of the mMEPS and SEPs is presented in Figure 5, in which lesions of perforating branches to

the internal capsula supplying the CT were damaged with consecutive mMEPs lost but leaving SEPs intact. This translate in what is referred to as "pure motor hemiplegia" in the postoperative clinical picture.

The D wave collision technique with intraoperatively CT mapping of the spinal cord

Further methodological development of recording D waves has brought a new methods in intraoperatively mapping the CT within the spinal cord (collision of the D-wave) (Deletis, 2006). This technique allowed us to intraoperatively map and find the anatomical position of the CT within the surgically exposed spinal cord. It involves simultaneous TES of the motor cortex with concurrent stimulation of the CT from the surgically exposed spinal cord (Figure. 6).

 The D wave is elicited by TES and recorded them cranially and caudally to the spinal cord tumor. Simultaneous to TES, we stimulated the surgically exposed spinal cord (caudal to the tumor site) with a miniature bipolar hand held probe (#5522.010 INOMED, GmbH, Germany). The tips of the probe were 1 mm apart delivering constant current stimuli up to 2.5 mA in intensity, 0.5 ms in duration and repetition rate of 1 Hz. Whenever the stimulating probe was in a close proximity to the CT, the D wave elicited by TES collided with the "anti D wave" elicited by the spinal cord stimulation. This collision resulted in diminished amplitude of the D wave recorded cranially to the lesion after collision This technique helps the surgeon to localize CT with spinal cord and modify resection of the spinal cord tumors (or other pathology) by "visualizing" CT tract position within the spinal cord.

Similar ways in CT mapping, as the previously mentioned collision technique, have been used during cerebello-peduncular tumor surgeries which are often burdened with a high incidence of CT lesioning resulting in post operative hemiplegia (Figure 7). Usually, the initial incision to the cerebellar peduncle results in a lesion to the CT.

Mapping of Cranial Nerves Motor Nuclei at the floor of the Fourth Vertricle

During surgery for cervical medullary junction tumors, the medulla and brainstem are high risk lesions to the cranial nerve motors nuclei, in addition to other very important and condensed structures in these miniscule anatomical spaces. The main features of these methodologies are presented in Figure. 8. Figure 9 presents a typical case for monitoring this type of surgery and follows each of the main steps of this procedure.

Figure 10, taken from the work of Dr. M. Morota, are typical examples of anatomical displacement of upper and lower cranial nerve motor nuclei due to the growing pattern of the brainstem tumors.

Monitoring of Corticobulbar motor evoked potentials (CoMEPs)

In order to overcome the advantages of the cranial nerve motor nuclei mapping methods, a new method has been developed to continuously monitor its functional integrity. This method operates with TES of the motor cortex and subcortical motor pathways with recordings of coMEPs from the muscles innervated by motor cranial nerve (Fig. 11). Further refinement of this methodology is monitoring of coMEPs for vagal nucleus together with monitoring of the functional integrity of the vagal nerve. Details of placement recording through "hook-wire electrodes" in the vocal muscles, after patient was intubated, are presented in Fig. 12.

Somatosensory Evoked Potentials (SEPs)
This method along with brainstem auditory evoked potentials (BAEPs) is one of the oldest ION methods. After more than a half century of use and a tumultuous beginning of non-fulfilled expectations that they could predict injury to the motor system, SEPs have come ahead and established its value as a) an excellent predictor of the cortical ischemia, b) an intraoperatively finder of the central sulcus (Figure. 13) and c) the guideline for shunt placement during carotid endarterectomy.

We should not underestimate the value of this method, and should be restrained as the indicator of the functional integrity of the sensory but not motor system.

Intraoperative Neurophysiological Mapping of the Dorsal Columns of the Spinal Cord

One of the interesting views of SEPs is the dorsal column mapping method. This methodology can determine the anatomical position of the dorsal fissure and can correctly indicate a myelotomy, especially in surgeries for syringmyelic cist and its the shunt placement (Figure 14).
      Dorsal column mapping (DCM) is based on two basic principles: First, evoked potentials traveling through the dorsal columns can be recorded. Second, the site of the recording electrode where the maximum amplitude is recorded represents the point on the electrode in closest proximity to the dorsal columns. For recording these traveling waves, a miniature multi-electrode is placed over the surgically exposed dorsal columns of the spinal cord. This electrode consists of eight parallel wires, 76 μm in diameter, 2 mm length, placed 1 mm apart and embedded in a 1 cm^2 (approximately) silicone plate. An extremely precise amplitude gradient is observed as the conducted potentials pass beneath the electrodes after right and left tibial and median nerve stimulations. The amplitude gradient of the conducted potentials indicates the precise location of the functional midline corresponding to the dorsal fissure of the spinal cord (i.e., usually the

optimal site for myelotomy). This data can be used by the neurosurgeon to prevent injury to the dorsal columns, which could occur through an imprecise midline myelotomy. Thus, it is especially useful during surgery for intramedullary spinal cord tumors or during spinal cord incision for the placement of a shunt for draining syringomyelic cysts. The use of a ND;YAG handheld laser (SLT, Montgomeryville, PA) with a 200 μm tip for myelotomy is a prerequisite for optimal results and for avoiding collateral thermal and physical damage to the dorsal columns

Intraoperative monitoring of the sacral nervous system

A relatively high percentage of pediatric surgical pathology is of the lumbosacral (LS) spinal cord and sacral roots within the cauda equina, where the LS nervous system could be damaged. In the last few years, effective methods for the intraoperative testing of the LS nervous system have been developed. We have had much success with these and will describe each in detail. From a didactic standpoint, we have categorized these methods based on recordings of neurophysiological signals of sensory systems ("afferent events") and recordings of signals from motor systems ("efferent events"). In intraoperative monitoring practice, they have been incorporated in one set of monitoring protocols (Figure 15)..

Afferent events
After electrical stimulation of the dorsal penile or clitoral nerves, a variety of neurophysiological signals can be recorded along the sensory pathways conveying this information to the brain. Recording of cerebral somatosensory evoked potentials from the scalp after such stimulation has been shown to be very useful in the testing of patients with sacral involvement. Unfortunately, due to its high sensitivity to anesthetics, it cannot be used intraoperatively.

DRAP (dorsal root action potentials)
(see Figure. 15, inset 2)
Recording of the DRAP of pudendal nerve afferent fibers, or the "pudendal neurogram" (the more frequently used term), is the mapping method most frequently used for selective dorsal rhizotomy to relieve spasticity in children with cerebral palsy
In this surgery, the DRAP is used to quantify the amount of pudendal afferent fibers coming from dorsal penile or clitoris nerves and entering the spinal cord via each of the S1, S2 and S3 dorsal roots. The DRAP is evoked by electrical stimulation of the penis or clitoris via two cup electrodes fixed on the dorsal surface of the penis or one on the clitoris and another on the adjacent labia. For recording DRAP, the surgeon frees a dorsal root and isolates it from its neighbors by lifting it outside the spinal canal using a hand-held bipolar hook electrode.
For the purpose of SDR, an S2 root is spared if it carries pudendal afferents. If it is essential to cut the S2 root it can be avoided it by dividing it into rootlets and cutting only those that do not carry pudendal afferent fibers.

In the recent study in 105 CP children, it was shown that the distribution of pudendal afferents in individual patients was highly asymmetrical (with respect both to side and sacral roots). One of the most striking aspects of this asymmetry was that 7.6 % of patients in this series had all pudendal afferent fibers (from the right and left pudendal nerves) entering the spinal cord via only the S2 roots. These data could explain the significant urogenital and sexual dysfunction after relatively restrained injury to the sacral roots. We suggest that mapping the DRAP during SDR be mandatory if S2 roots are considered for lesioning. Furthermore, we suggest that this method should be used in any surgery where S2 roots could be damaged.

Pudendal somatosensory evoked potential (SEPs)- Stationary wave
(see Figure.15, inset 3)
This potential obtained by electrical stimulation of dorsal penis/clitoris nerves, sometimes called spinal segmental response, could be very easily recorded when the conus region and root entry zone from S2 to S4 roots is exposed. If an electrode is placed precisely over this anatomical structure, high amplitude potential could be recorded, representing activity of the interneurons of the gray matter of the S2 to S4 spinal cord segment generated by sensory afferents form bilateral dorsal penis/ clitoris nerve.

Pudendal somatosensory evoked potential (SEPs) - traveling waves
(see Figure. 15, inset 1)
This potential is very rarely recordable from the dorsal column of the spinal cord , and has a rather low amplitude (1-2 µV) . Due to the rare recordability and low amplitude we did not find this potential suitable for intraoperative monitoring of the sacral nervous system integrity.

Efferent events
Three kinds of motor events can be recorded intraoperatively from the motor part of the sacral nervous system: motor evoked potentials from the anal sphincter (anal MEP), the M-wave after direct stimulation of motor roots of the cauda equina, and the bulbocavernosus reflex. Each of these events represents a different kind of activity that belongs to the motor part of the sacral nervous system.

Anal sphincter M-wave
(see Figure.15, inset 4)
Mapping of the S1, S2 and S3 motor roots that contribute to the motor part of the pudendal nerves can be easily performed by directly stimulating the exposed cauda equina by a hand-held probe and recording the electrical activity from the anal sphincter muscle (anal M-wave) through tiny wire hook electrodes inserted preoperatively in the right and left hemisphincter muscles. The mapping motor sacral roots within the cauda equina can be very useful in detecting a "hidden" root within the tumor or testing the phylum terminale for adherent sacral roots during untethering of a tethered spinal cord.

Anal MEP (Anal sphincter muscle-MEP)
(see Figure.15, inset 5)

This efferent response from the anal sphincter can be elicited and monitored by transcranial electrical stimulation over C1/C2 scalp points, in the similar fashion as TES for eliciting MEPs from the limb muscles. The recorded response indicates the functional integrity of the descending pathways for suprasegmental volitional control to the anal sphincter, as well as the motor part of the pudendal nerves, from anterior horn to anal muscle. Sometimes deep anesthesia can be an obstacle for eliciting anal MEP.

<u>Bulbocavernosus reflex</u> (BCR)
(see Figure. 15, inset 6)
The BCR is an oligosynaptic reflex mediated through the S2- S4 spinal cord segments, elicited by electrical stimulation of the dorsal penis/clitoris nerves with the reflex response recorded from any pelvic floor muscle. The afferent paths of the BCR are the sensory fibers of the pudendal nerves, its reflex center is the S2-S4 spinal segment, and the efferent paths are the motor fibers of the pudendal nerves and anal sphincter muscles. In neurophysiological labs, the BCR is usually recorded from the bulbocavernosus muscles, and this is where it gets its name. The advantage of BCR monitoring is that it tests the functional integrity of three different anatomical structures: sensory and motor fibers of the pudendal nerves, and gray matter of the S2-S4 sacral segments. A preserved reflex indicates the preserved integrity of all of these structures. Also, this reflex can be recorded in babies as young as 24 days.

Mapping and monitoring other sensory and motor roots within cauda equina

Other motor roots of the cauda equina (L1 to S1) can be mapped by recording the M-wave after electrical stimulation of the exposed cauda in a similar fashion as for the anal M-wave. The electrical activity from the appropriate myotomes should be recorded.

By electrical stimulation of the tibial nerves at the ankle or popliteal fossa, recording of the stationary wave over conus can be achieved. Furthermore, the traveling waves can be recorded more proximal over the spinal cord. This can be done with the identical electrodes as for pudendal SEPs. By using these methods, monitoring of the sensory roots of the cauda equina, dorsal horns, and dorsal columns can be achieved.

Brain Stem Auditory Evoked Potentials (BSAEP)

The physiological basis of (BSAEP)
BSAEP represents far field electrical activity recorded from the auditory nerve and brain stem auditory nuclei and pathways. BASAEP consists of the seven waves generated by different parts of auditory pathway and nuclei, but for the practical use only firs five is important. This definition encompasses only a short latency of BSEAP. Each off main five waves in BSAEP is generated by one or more anatomical structures within brainstem. Therefore their latency and appearance can intraoperatively indicate functional integrity of the mainly dorsal part of the brainstem, where those generators are located. Methodology for continuous intraoperative monitoring of the BSEAP is mainly used during surgery for: acustic neurinomas, posterior fossa surgeries, as well during surgery for microvascular decompression in trigeminal neuralgias.

It has been accepted that interpeak latency between wave I and III represent functional status of the acoustic nerve , while III to V wave interpeak latency functional integrity of the dorsal part of the brain stem from the striae medullares to the inferior coliculi.

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Figures caption

Figure1.

Upper: Schematic (left) and actual illustration (middle) of electrode placement for transcranial electrical stimulation and direct stimulation of the motor cortex (right). C1, C3, Cz, C2, C4 are the positions of the stimulating electrodes aligned over the projection of the motor strip to the head. Upper right is the schematics of the coronal posterior view to the motor cortex (in red) and corticospinal tracts (in pink) with an electrical field between the stimulating electrodes. Schematics of the grid electrode (right) overlying the exposed motor and sensory cortexes **Middle**: Schematic diagram of the positions of the catheter electrodes (each with three recording cylinders) placed cranially to the tumor (control electrode) and caudally to the tumor to monitor the descending signals after passing through the surgery site (left). In the middle are D and I waves recorded rostrally and caudally to the tumor site. On the right the placement of an epidural electrode is depicted percutaneously or through a flavectomy/flavotomy or when the spinal cord is not exposed. **Low:** Recordings of MEPs from the thenar, tibial anterior and abductor hallucis muscles after eliciting them with multipulse stimuli applied either transcranially or over the exposed motor cortex. *(Modify from : Deletis 2002)*.

Figure 2.

Neurophysiological monitoring during surgery for ISCTs. Incision of the dorsal median raphe (left panels): myelotomy is carried out by using a fine blade or laser. In spite of any attempts to stay within the median raphe (Panel I) to avoid damage to the dorsal column, SEPs are frequently compromised or loss during this surgical step (Panel II). Although the drop in amplitude is usually reversible, SEPs may remain unmonitorable for several hours. Removal of the tumor (right panels): there is direct access to the tumor after dorsal columns are separated. If there is no adequate lateral visualization to safely remove the tumor without excessive retraction to normal neural tissues, ultrasonic aspiration can be used to debulk the central part of the tumor (Panel III). At this point it is possible to gently dissect the tumor from the neural tissue. In doing so, traction on the corticospinal and other descending motor tracts can occur (Panel IV). Accordingly, muscle MEPs as well as epidural MEPs (Dwave) should be strictly monitored during this surgical step. The upper right panel shows the disappearance of the left tibialis anterior MEP during tumor removal. The lower right panel illustrates a stable D-wave, which warrants good long-term motor outcome (see text for more details.) Finally, the ventral part of the tumor is detached from the anterior spinal cord where perforating vessels from the anterior spinal artery are located (Panel V). Here again it is critical to monitor motor pathways since a vascular injury to the cord may result in an irreversible severe motor deficit.

Figure 3.
Principles of MEPs interpretation during surgery for intramedullary spinal cord tumors. *(From: Deletis, 2001)*

Figure 4.
Principles of MEPs interpretation during supratentorial surgery. *(Modify from: Yamamoto et al., 2004, and Fujiki et al., 2006)*

Figure 5.
A new motor deficit resulting from a subcortical stroke, following the perforating manipulation reflected by the loss of transient MEPs and the subsequent deterioration of MEPs, despite stable SEPs. Thenar MEPs and median nerve SEPs were recorded during dissection and clipping of an aneurysm on the basilar artery, superior cerebellar artery and the posterior communicating artery (PCOM) infundibulum via right pterional approach. MEPs impairment with no changes in the parameters of SEPs occurred during manipulation of perforators from the PCOM. Postoperatively, the patient experienced a new slight hemiparesis, and brain CT scans revealed a small basal ganglia infarction. *(From: Neuloh and Schram, 2002)*

Figure 6. Mapping of the CT using the D wave collision technique (see text for explanation):
A) S1=Transcranial Electrical Stimulation (TES). S2=Spinal Cord Electrical Stimulation. D1=Control D wave (TES only). D2=D wave after combined stimulation of the brain and

spinal cord. R=The cranial electrode for recording the D wave in the spinal epidural space. To the right: A tip of the hand held stimulating probe with a scale in millimeters. B) To the left: Negative mapping results (D1=D2). To the right: positive mapping results (D2 wave amplitude significantly diminished after collision).
C) Intraoperative mapping of the CT within spinal cord in 44 year old patient with intramedullary arterio-venous malformation at T3-T5 level. Stimulating probe delivering 2.5 mA current pulse in the close proximity with CT, revealed by a decrement of the D2 wave in comparison with D1 wave (control). *(Modified from: Deletis and Camargo, 2001)*

Figure 7. Mapping and monitoring of the corticospinal tract (CT) during surgery to remove a left cerebral peduncle tumor in a 27 year-old woman. **Bottom left**: Preoperative axial view of T1-wighted MR image with gadolinium documented complete removal of the tumor. The incision was placed in the area where no response to the stimulation of the cerebral pedunculus was recorded. (See above). Postoperatively, the patient had preserved preoperative motor function. **Top right:** Mapping of the CT on the cerebral peduncle is shown schematically. The cerebral peduncle is being mapped by a hand-held monopoloar probe. As the probe neared the CT, responses were recorded from epidural catheter (middle right). Responses were consistently repeatable. Stimulation intensity was 2 mA, stimulation rate was 4 Hz, and 4 responses were averaged**. Middle left:** Monitoring of the CT during tumor resection. After CT mapping, MEPs were continuously monitored by recording D waves epiduraly after transcranial electrical stimulation. The D waves remained stable throughout the procedure. *(From: Deletis, 2000)*

Figure 8.
Mapping of the brain stem cranial nerve motor nuclei. On the upper left is a drawing of the exposed floor of the fourth ventricle with the surgeon's hand-held stimulating probe in view. In the upper middle are depicted the sites of insertion of wire hook electrodes for recording the muscle responses. To the far upper right are compound muscle action potentials recorded from the orbicularis oculi and oris muscles after stimulation of the upper and lower facial nuclei (upper two traces) and from the pharyngeal wall and tongue muscles after stimulation of the motor nuclei of the operating microscope with hand stimulating a floor of the fourth ventricle (F) Caudal to aqueduct Silvii (A). *(From: Deletis et al., 2000)*

Figure 9.
Neurophysiological mapping of the floor of the fourth ventricle. A-B: sagital and axial MR T1-weighted images of a 24-year old female harboring a hemorrhagic pontine cavernoma. The patient underwent surgery in semi-sitting position. After opening of the dura, an extensive neurophysiological mapping of the floor of the fourth ventricle was performed. CMAPs were recorded from muscles innervated by the right (R) and left (L) facial nerves. U= upper, i.e. orbicularis oculi; L = lower; i.e. orbicularis oris. Panels C—F left to right: stimulation intensity thresholds, CMAPs and stimulation site on the floor of the fourth ventricle.

Anatomy of the dorsal aspect of the brainstem is completely distorted by the cavernoma. Midline is shifted to the left and there are dyschromic areas on the ependyma. Panel C: when stimulating the dyschromic area in the lower pons, CMAPs are obtained from RU and RL at 0.5 mA. This threshold significantly increases up to 2mA when stimulation is moved upward, where one would expect facial motor nuclei according to normal anatomy (Panel D). Panel E: moving stimulation downwards and to the left side, threshold drops again to 0.7mA but still elicits CMAPs from right side muscles. Finally, moving the hand-held probe to the far left, CMAPs from left side muscles are elicited at a very low intensity (0.4 mA).G: schematic drawing summarizing mapping results.

Facial nerve motor nuclei appeared to be significantly displaced caudally with respect to the location where they were expected according to normal anatomy. Moreover, left nuclei were displaced very laterally and the physiologic midline was also moved to the left. The safest entry-point turned out to be located in the upper pons. It is noteworthy that, without mapping, the surgeon would have been tempted to enter the brainstem in the area of more marked dyschromia of the ependyma, since one would expect this route to give the shortest access to the cavernoma/hematoma. Interestingly, as seen in panel C, this area corresponds to that with one of the lowest thresholds (0.5 mA) and entering the brainstem here would have likely resulted in postoperative facial palsy.

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Figure 10.
Typical patterns of cranial nerve motor nuclei displacement by brain stem tumors in different locations. **Upper and lower pontine tumors**: Pontine tumors typically grow to push the facial nuclei around the edge of the tumor, suggesting that a precise localization of the facial nuclei before tumor resection is necessary to avoid their damage during surgery. **Medullary tumors:** Medullary tumors typically grow more exophytically and compress the lower cranial nerve motor nuclei ventrally; these nuclei may be located on the ventral edge of the tumor cavity. Because of the interposed tumor, in these cases mapping before tumor resection usually does not allow identification of cranial nerve IX/X and XII motor nuclei. Responses, however, could be obtained close to the end of the tumor resection when most of the tumoral tissue between the stimulating probe and the motor nuclei has been removed. At this point, repeated mapping is recommended because the risk of damaging motor nuclei is significantly higher than at the beginning of tumor debulking. **Cervicomedullary junction spinal cord tumors:** These tumors simply push the lower cranial nerve motor nuclei rostrally when extending into the fourth ventricle *(From Morota et al., 1996).*

Figure11.
Schematics in intraoperatively eliciting and recordings of corticolbulbar motor evoked potentials (MEPs from muscle innervating by motor cranial nerves). Lower left: Schematic of positioning stimulating electrode over the scalp. Upper left: Schematic of corticolbulbar pathways innervating motor cranial nerves nuclei. (VII, IX, X, XII) Middle: positioning of recording electrodes inserted in orbicularis oris (N VII), pharyngeal (N IX), tongue (N XII) and vocal muscles (N X) for monitoring corticobulbar MEPs. To the right: typical examples of CoMEPs recorded from cranial motor nerves innervated muscles.

Figure 12.
Composed photograph of the larynx with the endotracheal tube (middle): A: Needles with hook wire electrode. B: hook wire electrode placed in the right vocalis muscle. C: insertion of the electrode through the rigid laryngoscope. D: recording of the CoMEPs from vocalis muscle (SLR).

Figure 13.
 Identification of the central sulcus obtained by the phase reversal of the median nerve cortical somatosensory evoked potentials. To the right is a schematic drawing of the exposed brain surface with a grid electrode position orthogonally to the central sulcus. On the left are the recorded evoked potentials phase reversed between electrode 6 and 7, showing a "mirror image" of the evoked potential between motor and sensory cortex, depicting the central sulcus lying between electrodes 6 and 7. *(From: Deletis, 2001)*

Figure 14.
Dorsal column mapping in an 18 year old patient with a syringomyelic cyst between the C2 and C7 segments of the spinal cord. Upper right: MRI showing syrinx. Lower middle: placement of miniature electrode over surgically exposed dorsal column; vertical bars on the electrode represent the location of the underlying exposed electrode surfaces. SEPs after stimulation of the left and right tibial nerves showing maximum amplitude between electrodes 1 and 2 (lower left and right). This data strongly indicates that both dorsal columns from the left and right lower extremities have been pushed to the extreme right side of the spinal cord. Using this data as a guideline, the surgeon performed the myelotomy using a YAG laser through the left side of the spinal cord and inserted the shunt to drain the cyst (upper middle). The patient did not experience a postoperative sensory deficit. *(From: Kržan, 2002)*

Figure 15.
Neurophysiological events used to intraoperatively monitor the sacral nervous system. *Left*, "afferent" events after stimulation of the dorsal penile or clitoral nerves and

recording over the spinal cord: (1) pudendal SEPs, traveling waves, (2) pudendal DRAPs, and (3) pudendal SEPs, stationary waves, recorded over the conus. *Right*, "efferent" events: (4) anal M wave recorded from the anal sphincter after stimulation of the S1–S3 ventral roots, (5) anal motor-evoked potentials recorded from the anal sphincter after transcranial electrical stimulation of the motor cortex, and (6) bulbocavernosus reflex obtained from the anal sphincter muscle after electrical stimulation of the dorsal penile or clitoral nerves. *(From: Deletis, 2001).*

Figure 16.
Six characteristic examples of DRAP showing the entry of a variety of pudendal nerve fibres to the spinal cord via S1-S3 sacral roots. A) Symmetrical distribution of DRAPs confined to one level (S2) or three levels (D). Asymmetrical distribution of DRAPS confined to the side (B), only one root (C or F), or all roots except right S1. Recordings were obtained after electrical stimulation of bilateral penile/ clitoral nerves.
(From:Vodušek and Deletis. 2002).

Figure. 17.
 An auditory pathway drawing within the anatomy of the brain stem with BSAEPS generators. CN = Cochlear nuclei, SOC = superior cochlear complex, LL= lateral lemniscus, IC=inferior coliculus. MGB= medial geniculate body, BIC=brachium of inferior coliculus. (*From: Møller, 2006*)

Figure 18.
Inraoperative BSAEP to the right ear stimulation recorded during surgery for a right acoustic neuroma, showing before (upper) and after retraction of cerebellum. The most prominent change in BSAEP was an increase in the I to III waves interpeak interval of more than 1 ms, reflecting a stretching of the eight nerve. The smaller change in the III to V interpeak interval may reflect an effect of the retraction on the brainstem. (*From: Legatt, 2002)*