ABSTRACTS OF SCIENTIFIC PAPERS SECOND INTERNATIONAL SYMPOSIUM ON CENTRAL NERVOUS SYSTEM MONITORING

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The following represents the proceedings from the Second International Symposium on Central Nervous System Monitoring, held in Gmunden, Austria, September 8 and 9, 1989. As was the first Symposium, this meeting was eclectic, with many different disciplines represented. In addition, the Symposium consisted partly of tutorials and partly of scientific papers. Thus, it offered a unique educational and scientific experience. These abstracts offer only a taste of that experience, and the interested reader should contact the individual authors.

For the American reader, the abstracts offer a glimpse of what is going on in other countries, particularly European countries, in this important area. It is obvious that the Europeans have accumulated a vast amount of valuable clinical experience, with a wide variety of central nervous system monitoring techniques.

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CENTRAL NERVOUS SYSTEM MONITORING FOR DIAGNOSIS AND CONTROL OF THERAPY

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Within the intensive care unit, central nervous system monitoring primarily serves to identify intracranial complications and to control the success of therapy. During surgery, cerebral monitoring not only permits anesthesia regulation, but, with interventions in the brain or the cerebral circulation, it also permits the assessment of the effect of certain measures and a selective avoidance of lasting damage.

Therefore, monitoring in the intensive care unit and the operating theater will require many different kinds of variables. In the intensive care unit, the identification of anything that can occupy intracranial space is paramount; the most important variables will therefore be intracranial pressure and cerebral perfusion pressure. Electrophysiology and, for example, transcranial Doppler sonography are useful for the assessment of cerebral vasospasm. In the operating area, the focus is on the use of monitoring with computer-assessed electroencephalographic (EEG) and selected evoked potentials for the earliest identification of an ischemic or directly pressure-related danger to the brain, again supplemented by transcranial Doppler sonography.

Monitoring of intracranial pressure should preferably be effected by minimally invasive, miniature sensors directly implanted intracranially. Compared with ventricular pressure measurement, which is limited to use with special indications (cerebrospinal fluid drainage, for example), the above method is less prone to artifact production and cannot cause infections. The intracranial pressure sensor by Hellige, constructed with a cavity resonator, has been shown to be reliable in comparative tests but is difficult to implant. More simple to implant, but less exact, are the microcatheter-type miniature sensors (Gaeltec, Philips) and, more recently, intra-parenchymal fiberglass pressure recording by means of the Camino-pressure system. A computer-supported evaluation is also meaningful because of the wavelike pressure dynamics (long-term graphs, histogram statistics), used also for perfusion pressure calculation, in

which pressure recording in the temporal artery proved useful as a reference of carotid pressure. Pressure recording allows diagnosis for operation, from decompression trepanation to the regulation of conservative therapy.

For our purposes, the currently available electrophysiologic monitoring was found to be suboptimal. We therefore developed a special eight-channel EEG computer system with integrated evoked potentials. This supplied useful intraoperative information, particularly in cerebrovascular neurosurgery. For example, intraluminal shunts, implantation of extra-intracranial bypasses, and media-thromboendarterectomy, which was made safe only by the use of this method, were all regulated by means of computer-supported EEG and evoked potential analysis. Since the introduction of this system 2 years ago, no lasting neurologic deficits have appeared after cerebrovascular neurosurgery (carotid stenoses, vertebral stenoses, intracranial vascular stenoses, bypass surgery).

The transcranial Doppler can also be used for continuous monitoring with a fixed flat probe. In the intensive care unit, this permits testing of therapy effects with vasospasm and is an important aid in the determination of cerebral death. In the operating theater, continuous flow regulation complements electrophysiologic monitoring, particularly in carotid artery surgery.

INFLUENCE OF ANESTHETICS ON BLOOD FLOW VELOCITY OF CEREBRAL CIRCULATION

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Owing to continuing technical developments in the area of cardiopulmonary function, monitoring perioperative patient safety has attained high levels. Central nervous system monitoring, however, has lagged, partly owing to a lack of acceptance of suitable methods. This, in turn, was due to difficult development, invasiveness, problems of interpretation, and high costs.

The inclusion of transcranial Doppler sonography in perioperative anesthetic monitoring has opened up new opportunities for the assessment of the reactivity of cerebral vessels to CO_2, despite some reservations about the method. The method's advantages are obvious: quick, noninvasive, regionally specific, continuous, applicable anywhere, and repeatable at will. In contrast, one must consider the important disadvantage: it is velocity that is being measured.

Before clinical use in anesthesia, at least two problems need to be solved: (1) To what extent does the Doppler-sonographic signal represent known alterations in cerebral perfusion under diverse anesthesia conditions? and (2) Is it possible to draw conclusions regarding autoregulation and reactivity of cerebral vessels to CO_2 by means of this method?

With regard to the first question, we examined a total of 45 patients in three groups, each receiving a different anesthesia agent regimen: modified neuroleptic analgesia (midazolam/alfentanil), ataral analgesia (ketamine/midazolam), or thiopental. In each case, recordings were undertaken within the area of the middle cerebral artery at three points in time with the patient supine: before premedication in a waking state, 20 minutes after preanesthetic medication (Thalamonal 0.03 ml/kg and atropine 0.01 mg/kg), and during anesthesia steady state after intubation and during controlled ventilation (P_{CO_2} = 36 mm Hg).

The following results were determined: mean flow velocity in all patients was 51.6 cm/s, flow velocity decreased with increasing age, mean flow velocity increased after preanesthetic medication (+11%), and, in all of the anesthetic procedures mean flow velocity reflected the changes in cerebral perfusion.

To clarify the question of cerebral reactivity to CO_2 and autoregulation, we studied the reaction of the vMCA to CO_2 alterations and to increases in arterial mean pressure in an additional 7 patients during 1 vol% isoflurane (60% N_2O/40% O_2 in steady state, 30 minutes after induction of anesthesia). The results demonstrated largely retained autoregulation and reactivity to CO_2 when isoflurane was 1 vol% or less.

Apart from the already established potential for the application of transcranial Doppler sonography in neurology and neurosurgery, this method provides a new potential for the monitoring of cerebral O_2 supply in postoperative anesthetic care, particularly in combination with already established monitoring systems.

ASSESSMENT OF THE PROTECTIVE EFFECTS OF ANESTHETIC AGENTS

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Although the precise mechanism subserving the state we define as "anesthesia" has yet to be clarified, it is clear that, in simple terms, "anesthetic" agents induce unconsciousness by primarily suppressing cortical function. This is evident by alterations in cortical electrical activity and, since function is depressed, by decreases in the requirement for oxygen and the utilization of glucose. Since the demand for energy substrates is usually decreased in the anesthetized individual, it has been suggested that those anesthetic agents that suppress cerebral metabolism could have a role in protecting the brain in those pathologic situations in which the supply of energy substrates is reduced (or the demand increased). Although this appears to be a reasonable hypothesis, it is probably an oversimplification of a complex issue, particularly since anesthetic agents have "vascular" as well as "metabolic" effects.

Propofol is an anesthetic agent that is effective when administered as a single injection, as intermittent boluses, or in an infusion. It is known to decrease the cerebral metabolic rate for oxygen and, consequently, could—at least theoretically—have "protective" properties. The present communication will consider this possibility by characterizing the effects of propofol noted in a number of investigations (experimental and clinical) designed to examine a variety of clinically relevant situations.

The investigations demonstrate that propofol decreases metabolic demand (alterations in spontaneous electrical activity; dose-dependent decreases in cerebral metabolism) and can decrease to lower values of mean arterial pressure, the threshold at which extracellular potassium concentration increases in a model of incomplete global ischemia. However, the effect of propofol per se was less clear in a model of focal ischemia (middle cerebral artery occlusion). In patients without intracranial pathologic evidence of disease, propofol has been shown to suppress spontaneous cerebral electrical activity, and the effect, if any, of this property is currently being investigated in patients undergoing cardiopulmonary bypass.

Obviously, it will not be possible to compare directly each of the studies. However, results of such a "package" of studies using a single agent may throw some light on the question of whether anesthetic agents have protective effects as far as the brain is concerned.

PATHOPHYSIOLOGIC MECHANISMS OF SECONDARY BRAIN DAMAGE

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The contribution of secondary brain damage to negative outcome from acute cerebral insults, such as cerebral ischemia or severe head injury, can hardly be overestimated. A clear understanding of the pathomechanism involved is a requirement for the development of more effective forms of prevention and treatment. Extracranial and intracranial causes of secondary brain damage can be distinguished. Major *intracranial* manifestations of secondary injury to the cerebrum are associated with an intracranial mass, such as brain edema, hemorrhage, or severe vasocongestion, leading to intracranial hypertension with its deleterious consequences. These consequences include secondary ischemia and herniation of the brain as an ultimate cause of poor outcome. A more profound understanding of the processes underlying formation of brain edema is mandatory, including their vasogenic and cytotoxic modifications, opening of the blood-brain barrier, or secondary impairment of the microcirculation. Release and activation of highly active mediator compounds in damaged brain tissue must also be mentioned in this context.

Systemic hypoxia from acute ventilatory failure and cardiovascular insufficiency from major blood loss are the most important *extracranial* mechanisms leading to secondary brain damage. Prevention of brain damage from these extracranial causes is largely a matter of competent emergency care and logistics in the prehospital phase. This is an important point because deficiencies and failures of emergency care are significant contributions to poor outcome, part of which is avoidable. Little information is available on this subject. Findings obtained in a retrospective analysis of autopsy cases of patients with severe head injury indicate that emergency care was deficient in about 50%. The problems encountered included stopping bleeding (10% of cases), adequate positioning of the patient (24% of cases), appropriate fluid substitution (24% of cases), and securing of ventilation (20% of cases). Besides, owing to a limited availability of neurosurgical beds, many patients with acute traumatic insults to the brain are referred to general trauma centers. This policy may be associated with a delay of diagnosing and treating intracranial space-occupying processes as another cause of secondary deterioration.

Improvement of the situation might be accomplished by more efficient implementation and organization of all measures required in the early prehospital phase, including referral to competent clinical centers for rapid diagnosis and treatment. Only then might specific measures, such as interference with the release and function of neurotoxic mediator compounds, improve the currently poor morbidity and mortality from acute cerebral lesions.

MONITORING OF GAS PRESSURE CHANGES IN THE BRAIN BY DC POTENTIAL MEASUREMENTS

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Epicortical and epicranical DC potential changes were studied during episodes of hypoxia, hypercapnia, and primary asphyxia. The experiments were performed in anesthetized and artificially ventilated rats.

Hypoxia induced by a decrease in FiO_2 was associated with a negative displacement of the cortical DC potential. With a critical lowering of the O_2 content, the negative variation of the DC potential turned into a positive one.

Hypercapnia induced by an increase in the inspiratory CO_2 content elicited a positive shift of the cortical DC potential.

Primary asphyxia induced by an interruption of ventilation with air was characterized by a typical sequence of cortical DC potential changes: an initial negative phase, a transient positive phase, and a terminal negative phase. When the ventilatory arrest was terminated during the transient positive phase, an incremental reactive positive potential occurred.

Comparison of the DC potentials led from the cortical surface or from within the cortex with those led from the skull brought out several differences. The polarity of DC shifts during hypoxia and hypercapnia was found to be opposite with both sites of recording. During asphyxia, the prominent terminal negative potential could also be detected from the skull, whereas the intermittent positive potential was inverted.

INTRAPARENCHYMAL AND CONVENTIONAL MONITORING OF INTRACRANIAL PRESSURE

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A newly developed fiberoptic catheter has been used for monitoring intracranial pressure. Its construction allows intraparenchymal, subdural, and intraventricular measurement. We have used the catheter to measure intraparenchymal pressure in 15 consecutive patients with severe head injury, i.e., not responding to verbal stimuli and with eyes continuously closed. A protocol for treatment was set up, including patient's positioning, hyperventilation, mannitol, and, as a last resort, barbiturate therapy, to keep the intracranial pressure below 20 mm Hg.

After 6 months of follow-up, 9 of the 15 patients (60%) showed a good recovery according to the Glasgow coma scale. Two patients were moderately disabled and 3 were severely disabled. There were, however, no vegetative patients, and only 1 patient died. No infections, hematomas, or other complications due to the monitoring device occurred. The accuracy was good, with intraventricular pressure as a "gold standard." The drift was below 3 mm Hg in all catheters, indicating a high reliability. We conclude that the fiberoptic catheter for intraparenchymal brain pressure monitoring seems simple, safe, and accurate.

MINIATURIZED SENSORS TO RECORD METABOLIC VARIABLES

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The recording of physical variables, e.g., pressure and temperature, is routine in every intensive care unit. However, we lack the possibility of recording metabolic variables, such as blood flow, blood gases, blood electrolytes, and other clinically relevant variables.

Modern technologies, such as semiconductor and thin-layer technology, have made available a number of sensors that can be used for continuous recording in human medicine. Stereotactic thin-layer instruments have been successfully used during neurosurgical operations to record event-related potentials. By means of thin-layer sensors, temperature gradients can be recorded with great exactness and perfusion changes can be detected by the heat clearance method.

These recording instruments permit highly sensitive microperfusion determinations based on the heat clearance principle, with high local resolution and without any extensive tissue destruction.

Further developments concern miniaturized pH and potassium sensors, which have been successfully tested in nonheparinized whole blood. These sensors are intended to record electrolyte shifts in the cortex. Miniaturized thin-layer glucose sensors based on the glucose-oxidase enzyme are under development and in vitro studies have been able to cover the physiologic range with high sensitivity. These quickly reacting sensors are characterized by high storage stability and linear responsiveness.

LONG-TERM MONITORING OF SPONTANEOUS AND EVOKED BIOELECTRICAL BRAIN ACTIVITIES

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The spontaneous electroencephalographic (EEG) and evoked (evoked potential, EP) bioelectrical activities of the brain reflect the functioning of neuronal structures and systems. An automatic monitoring of the EEG together with different modality EPs gives continuous information regarding the cerebral state in unconscious and conscious patients; an improvement or deterioration of cerebral function can be detected very early.

The EEG reflects widespread neuronal cortical activity and depends on central medication and cerebral blood flow. Brain ischemia results in a characteristic slowing of the EEG. The brainstem auditory evoked potential (BAEP) reflects event-related changes in neuronal activity of the auditory pathway, including the brainstem, and is relatively stable under anesthesia and other drug influences. Therefore, BAEP monitoring is used preferably for surgical procedures in the posterior fossa and has also been recently used for monitoring comatose patients and brain death. The somatosensory evoked potential (SEP) is composed of different components, the most prominent being the cortical N20, and is affected by cerebral ischemia, thalamic lesions, and brainstem lesions. SEP recording from the upper cervical spine results in a component at about 14 msec. The difference between the cervical and first cortical component N20 is defined as central conduction time (CCT). Long-term monitoring of the CCT gives a cerebral input control (cervical SEP) and information about the somatosensory pathway, including brainstem, thalamus, and contralateral somatosensory cortex.

For a comprehensive study of different cerebral functions, including various neuronal structures and systems in cortex and brainstem, simultaneous long-term monitoring of EEG, BAEP, and SEP is necessary, together with the recording of respiratory, cardiovascular, and other physiologic variables. This type of polygraphic long-term monitoring can be used not only for monitoring comatose patients or during operative procedures, but also to study the time relationships of different cerebral variables and other variables during extreme cerebral conditions, such as hyperbaric oxygenation, anesthesia, or increased intracerebral pressure.

The technique of simultaneous long-term monitoring of EEG, EPs, and other physiologic variables was introduced by Maresch and associates [1]. Some of the first examples were reported by Pfurtscheller and colleagues [2] and Litscher and colleagues [3]. The present study reports examples of long-term EEG and EP monitoring under different conditions in the intensive care unit, operating room, hyperbaric chamber, and pediatric department, and shows that this form of comprehensive monitoring is already state of the art.

Multivariable, polygraphic long-term monitoring should be used to evaluate the reliability of individual signals for cerebral monitoring and to establish optimal warning and alarm criteria for critical situations with and without surgical interventions. The multivariable long-term monitoring technique is already available for use with personal computers [4] and can be performed under various clinical conditions in unshielded operating rooms and intensive care units. This technique should provide a better understanding of cerebral function under extreme physiologic and pathophysiologic conditions, reduce the patient's risk during surgical interventions, and allow a better management of patients in the intensive care unit.

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REFERENCES

1. Maresch H, Gonzalez A, Pfurtscheller G. Intraoperative patient monitoring including EEG and evoked potentials. In: Proceedings of XIV ICMBE and VII ICMP, Espoo, Finland, 1985:776–777
2. Pfurtscheller G, Schwarz G, Schroettner O, et al. Continuous and simultaneous monitoring of EEG spectra and brainstem auditory and somatosensory evoked potentials in the intensive care unit and the operating room. J Clin Neurophysiol 1987;4:389–396
3. Litscher G, Friehs G, Maresch H, et al. EEG and EP monitoring in the hyperbaric environment. J Clin Monit 1989; 6:10–17
4. Steller E, Litscher G, Pfurtscheller G, et al. EEG-EP monitoring system with PC. In: Proceedings of BME-Austria, 1988:89–92

SIMULTANEOUS ACQUISITION AND ANALYSIS OF MULTICHANNEL ELECTROENCEPHALOGRAPHIC AND EVOKED POTENTIALS FOR INTRAOPERATIVE MONITORING

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Background electroencephalographic (EEG) as well as somatosensory and far field acoustic evoked potentials (EPs)

have proven to be well suited for the intraoperative monitoring of brain function. Experience with more than 50 operations on the carotid artery in our institute has demonstrated the necessity of a simultaneous evaluation of both EEGs and EPs. To supply the surgeon with an appropriate device, we developed a personal computer–based neuromonitoring system. All of the following procedures are performed in real time.

Up to eight channels of EEG are acquired, displayed, stored on disc, and analyzed by means of a Fourier transform. Each of the eight power spectra is displayed in terms of a compressed spectral array together with the spectral edge frequency. In addition, up to three variables derived from the spectra may be displayed as a trend curve for a pair of channels selected by the operator. This feature was provided to facilitate the detection of focal ischemia.

Up to three EP channels are acquired, stored on disc, averaged (including visual artifact rejection), and displayed on the monitor.

Until now, the neuromonitor's results have been visually interpreted by the operator. During carotid surgery, e.g., guided by the neuromonitor's results, the surgeon can decide whether the artery may remain clamped during the operation.

By nature, visual evaluation of the online results is neither consistent nor reliable. Therefore, we shall probably add an automated trend-tracking algorithm to the system. An adequate framework for this problem is given by the theory of multistage Kalman filters. Reflecting the statistical behavior of appropriate spectral variables, the algorithm continuously yields probability values for the occurrence of various kinds of instabilities.

RADIOTELEMETRIC LONG-TERM MONITORING FOR PATIENTS EVALUATED FOR SURGICAL THERAPY OF EPILEPSY

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Since the electroclinical analysis of the patient's habitual seizures remains the significant step in the presurgical evaluation of a candidate for surgical therapy of epilepsy, special techniques of data acquisition, i.e., recording and transmission, become essential prerequisites to fulfill the increasing demands in terms of both time-span (long-term recording) and space (bedroom or even domiciliary recording). Furthermore, because this presurgical long-term monitoring depends critically on the simultaneous observation of the electroencephalographic (EEG) and clinical behavior, including polygraphic measurements which, for instance, monitor the functions of the autonomic nervous system, voluminous data are produced. These data require computer-aided data reduction and analysis.

Transmission of EEG signals from the subject to the recording apparatus or from the recording apparatus to the data acquisition or processing facility at a distant site can be by a signal lead (cable telemetry) or by radiotelemetry.

Except in the case of ambulatory EEG cassette recording, in which transmission and storage are intimately linked, the method of EEG storage need not depend on the technique of data transmission.

Besides the conventional paper write-out, EEG recording/storage on videotapes might make use of the audio channel of the same tape on which the behavioral information is contained, or might—after reformatting—be recorded on the same video image as the behavior. In contrast to videotapes, digital tapes and discs are more complex and expensive media. However, they have the advantage that data are stored in a format suitable for additional computer analysis.

Currently used methods of long-term combined EEG and video-audio monitoring vary from one center to another. This wide array of somewhat different methodologies reflects that this field is still in flux, being open to improvement as new technologies dealing with EEG signal analysis and video recording become available. Most centers have at their disposal cable telemetry or radiotelemetry, either with video-monitored beds in a specialized ward, i.e., designated monitoring rooms, or over those hospital areas that are wired to accommodate a patient being studied with cable telemetry. Moreover, portable 16-channel cable telemetry with video and 8- or 16-channel ambulatory cassette systems are used in parallel. Procedures that require minimal personnel and that are not labor intensive are obviously favored. Today, some kind of seizure detection methods should be an integral part of an advanced telemetry organization and are in fact realized at advanced centers.

In summary, integrated telemetry-computer-video systems can accomplish considerable data reduction. The computer may process the EEG in an attempt to analyze background activity and to recognize seizures and interictal spikes.

INTRAOPERATIVE ELECTROENCEPHALOGRAPHIC AND EVOKED POTENTIAL MONITORING—INDICATIONS, PATTERNS, AND AREAS OF INFORMATION

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Nearly 143 years follow the first successful use of ether as an anesthetic by Morton. In 1931, H. Berger described the coincidence of anesthetic-induced electroencephalographic (EEG) changes with altered corticoneuronal function level. Yet, problems regarding assessment of "depth" of anesthesia still exist. Moreover, the anesthetic use of induced hypotension and deliberate circulatory arrest requires a new understanding of tolerable limits of brain insults. For that reason, the monitoring of the brain as the primary site achieves priority over the methods of hemodynamic (pulmonary artery catheter) and ventilatory (pulse oximetry) control.

We examined the different electrophysiologic brain function monitoring systems in 30 patients (informed consent was given) undergoing trauma, orthopedic, or cardiovascular surgery. We wanted (1) to explore anesthetic drug regimens adapted to the preoperative state of the patient and to the type of operation; (2) to maintain a constant level of hypnosis and pain tolerance; (3) to detect the approach to critical threshold (23 ml/100 gm/min^{-1}) of cerebral perfusion, as well as the sudden risk of cerebral oxygen supply (clamping of cerebral vessels); and (4) to ensure the complete elimination of anesthetic drugs.

The central nervous system monitoring included (1) conventional EEG tracings (10 channels, 10/20 system); (2) microprocessed EEG (fast Fourier transform), compressed spectral array, and spectral edge frequency (SEF) with the Neurotrac; (3) aperiodic analysis, with each signal presented as a vertical symbol in a three-dimensional, color-coded manner,

and with the activity edge denoted by a white line (Lifescan); and (4) somatosensory evoked potentials (SSEPs), median, or tibialis posterior nerve stimulation. The variables for the latter included central conduction time (CCT), a latency difference of N20 to N14, and the value of N20/P25 amplitude (cortical primary complex).

Electroencephalographic monitoring of trauma surgery was performed to maintain constant anesthetic level (n = 30 patients, 18 to 53 years of age). Anesthetics compared included propofol, midazolam, isoflurane with etomidate, and alfentanyl. We wanted to ascertain the minimal infusion rate to prevent movement in response to surgical incision, to estimate cerebral distribution, to achieve and maintain a stable hypnotic stage, and to determine the time of drug elimination. Propofol initially demonstrated 2 Hz 200 μv^2 activity, with a succeeding stable phase at 12 Hz. Midazolam was characterized by 30 Hz, 200 μv^2 activation 10 minutes post infusion, with a succeeding stage at 18 Hz, 100 μv^2. Isoflurane showed an increase of 2 Hz activity 220 μv^2 6 minutes post inhalation and an unstable phase changing within the range of 15 to 22 Hz. Concerning time to reappearance of 20 Hz activity, 50 μv^2, combined with the return of psychomotor function, propofol 12 ± 3 minutes proved to be superior to isoflurane 16 ± 4 minutes and midazolam 40 ± 5 minutes.

The problem during EEG monitoring for Harrington instrumentation was to avoid paraplegia (n = 30 patients, 14 to 22 years of age). Anesthesia included dehydrobenzperidol, fentanyl, midazolam, and pancuronium. Monitoring included the raw EEG, as well as SEF analysis with the following goals: to accompany the wake-up test to examine motor cord function and to control the efficacy of the benzodiazepine antagonist flumazenil given to shorten the period of awareness. After instrumentation but without correction, 10 minutes after maximal distraction, the administration of flumazenil changed the hitherto stable 12- to 13-Hz rhythm to 20- to 30-Hz activity, with the patient obeying commands within 50 ± 10 seconds. Sufficient depth of anesthesia was reestablished by thiopentone 100 mg, fentanyl 0.10 mg, and isoflurane 0.4 to 0.6 vol%, as confirmed by bilateral 12-Hz rhythm. In view of potential complications and short period (10 to 20 minutes), recording of the SSEP offers an indirect but quantified evaluation of spinal cord function. Reduction of N20/P25 amplitude by 20% signals transient partial blockade; reduction by 50% signifies a high risk. When the amplitude of N20/P25 was reduced from 1.87 to 0.55 μV, the immediate inhibition of distraction then reestablished the amplitude to 1.60 μV.

The problem during EEG and evoked potential monitoring for open heart surgery (30 patients, 54 to 74 years of age) was to prevent secondary organic damage, in which the brain is involved in 1 to 70% of cases. Anesthesia consisted of fentanyl, flunitrazepam, 02-N20, pancuronium, and isoflurane. Recording of the raw EEG occurred during critical periods, such as post induction, partial bypass, onset of total bypass, nadir of hypothermia, weaning from echocardiogram, rewarming, and the postoperative period. The behavior of perfusion pressure proved to be the key factor in the deterioration of brain function in the presence of hypothermia. Flattening of the EEG occurred at a temperature of 29.1°C and a perfusing pressure of 41 mm Hg on partial bypass. Onset of total bypass with elevation of perfusion pressure to 50 mm Hg restored rhythm. The EEG is a sensitive indicator of the decrease of hypnosis and analgesia because of reduced plasma concentrations of anesthetics and, in our studies, indicated an increase in isoflurane concentration (0.6 to 0.8 vol%) and supplementation of fentanyl 0.10 mg. When burst suppression occurred during weaning from bypass (perfusion pressure, 49 mm Hg), elevation to 60 mm Hg by dopamine administration reestablished an 8- to 12-Hz rhythm. Spontaneous EEG activity ceased at 26°C, while SSEP potentials were available down to 22°C. During hypothermia at 24°C, we observed an increase of CCT to 8.49 msec, with a corresponding decrease of N20/P25 amplitude from 2.3 to 1.0 μV and recovery after rewarming to 26.6°C: CCT 7.81 msec, N20/P25 1.5 μV.

In conclusion, in cases in which there is a reduction in metabolism from anesthesia or hypothermia, or in which there are changes in perfusion volume or pressure and vascular resistance produced by drugs or artificial ventilation, EEG and evoked potential monitoring during the operative period represents a direct, objective measurement of brain function level. In addition, it opens the way to an individual, economic control and documentation of anesthesia, and provides the team with sensitive, reliable, and rapidly available data on brainstem and hemispheric function. Regarding the patient, it helps accomplish the ethical demand of perioperative preservation of corticoneuronal integrity, the source of intrinsic individuality.

USE OF ACOUSTICALLY EVOKED POTENTIALS TO RECORD DEPTH OF ANESTHESIA

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Objective measurement of depth of anesthesia is still an unsolved problem. When globally acting drugs were used to effect anesthesia, this deficiency was of little importance. The greater the use of balanced methods, in which the different components of anesthesia can be influenced singly with drugs acting with a great deal of variety, the more the questions of awareness turned into questions relevant not only medically but also legally. Any automation of the process of anesthesia can be developed further only when objective recordings of anesthesia depth become available.

Every attempt to describe anesthesia by means of pharmacokinetic models has failed. To solve the problem, only pharmacodynamic studies are likely to be successful. To describe functional states of neuronal systems objectively, so-called event-related responses have been shown to be most suitable. With regard to anesthesia initially, the somatosensory evoked potentials seem to be especially suited, because this method can be used to measure the primarily interesting aspect directly. In this regard, the somatosensory evoked potentials are seen to be a further development of the concept of minimum alveolar concentrations.

I have placed the acoustically evoked potentials in the focus of my interest, not because I believe that the power of hearing is closely correlated with the depth of anesthesia, but because any insights into the functional states of the brainstem can only be obtained with acoustically evoked potentials. Indeed, the receptors of those drugs that are used to obtain "balanced" anesthesia are found most often in the brainstem. It should be possible, with the aid of acoustically evoked potentials, to determine the location of effect, as well as the kinetics of the pharmacodynamics of opioids and benzodiazepines. I was unable to verify this hypothesis with the single-drug studies that I executed, so, at the conclusion of my studies, the measurement of the depth of anesthesia remains an unsolved problem.

ASSESSMENT OF RECOVERY OF SPINAL CORD FUNCTION USING SOMATOSENSORY EVOKED POTENTIALS AFTER THORACIC AORTIC CROSS-CLAMPING

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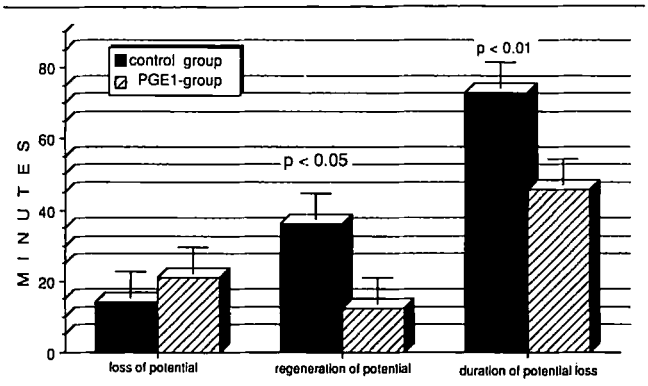
Numerous strategies with barbiturates, corticosteroids, calcium channel blockers, and/or superoxide dismutase are used for the protection of spinal tissue during stages of temporary ischemia. Prostaglandin E_1 (PGE_1) seems a promising new candidate, since it increases oxygen and glucose supply to the cell, releases the precapillary sphincter spasm during malperfusion, and inhibits the deleterious postischemic release of lysosomal enzymes. Thus, the effectiveness of PGE_1 in the prevention of postischemic paraplegia was tested in a near clinical condition using somatosensory evoked potentials (SSEPs) as an objective measurement during the reperfusion period, and the results with the postoperative neurologic outcome were compared.

Twenty-three beagle dogs weighing between 15 and 25 kg were divided into two groups. In group 1 (control, n = 11), the descending thoracic aorta was cross-clamped during enflurane anesthesia while the animal was ventilated to normocarbia. The clamping period lasted for 60 minutes and was followed by a reperfusion period for another 60 minutes. After recovery, the animals were observed for 7 days with regard to motor control of hind limbs, especially their ability to walk. The animals of group 2 (PGE_1; n = 12) were treated in a similar manner, except that 15 minutes before aortic cross-clamping, an infusion with PGE_1, 100 ng/kg/min, was given intravenously, which lasted until the end of the reperfusion period. The SSEPs were derived from spinal-evoked potentials using a pulse of 0.2 msec duration, 0.2 mA above motor threshold. A total of 265 sweeps were fed into a computer (Lifescan, Diatek, Inc, San Diego, CA) with a band width of 30 to 1,500 Hz, 3 db cut-off, and a sampling rate of 3.1 kHz. The amplitude of the major deflection around 50 msec post stimuli was computed by means of cursor positioning using peak-to-peak difference.

Clamping of the thoracic aorta resulted in a loss of SSEP amplitude within 15 to 20 minutes (Figure). In comparison with the control group, reperfusion in the PGE_1 group was characterized by an earlier return of depressed amplitude (see Figure). This effect was significant ($P < 0.01$) when compared with the control group.

Additionally, the number of animals able to walk in the postoperative period was statistically higher ($P < 0.01$) in the PGE_1 group (7 of 12, 58.3%) compared with the control group (1 of 11, 9%) (see Figure).

In conclusion, aside from a better postoperative neurologic outcome, the protective effect of PGE_1 correlated closely with a faster return of evoked potential ($r = 0.98$). Thus, SSEPs present a valuable tool during phases of aortic cross-clamping to predict neurologic outcome. Additionally, they can be used to evaluate the potential benefits of new agents for protection against ischemic events.



Time from clamping of aorta to loss of SSEP (left), *from unclamping to regeneration of SSEP* (middle), *and duration of loss of SSEP* (right).

CENTRAL NERVOUS SYSTEM MONITORING FOR THE THERAPY CONTROL OF SUBARACHNOID HEMORRHAGE

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Therapy for subarachnoid hemorrhage includes the treatment of (1) excessive pain, (2) increased intracranial pressure, (3) vasospasm, (4) ischemic stroke, (5) hypertensive crises, and (6) disturbances of the autonomic nervous system.

Analgesic therapy with high potent analgesics and sedatives is required to reduce pain and the concomitant sympathetic overactivity. It should be taken into account that the sympathetic overactivity and increased metabolism reduce the half-life of the drugs.

The monitoring of intracranial pressure (ICP) shows that two periods of high ICP can develop during the clinical follow-up. Via hypertension, the initial increase in ICP can be an additional cause of fatal rebleeding on the first day. Thus, in the acute situation, the reduction of ICP can be lifesaving. Secondary maxima are induced by the brain edema according to the vasospasm and ischemic lesions. The ICP can be augmented by a decreased absorption of the spinal fluid, and external drainage may be necessary. Reduction of ICP requires strict bed rest, infusions of glycerol or sorbitol, and/or assisted ventilation. At high ICP intensity, 50 gm glycerol has an effect of 3 hours and 50 gm sorbitol has an effect of only 1.5 hours. Glycerol is preferred, but careful monitoring of osmolality and blood sugar is necessary.

The monitoring of vasospasm can be easily performed by transcranial Doppler sonography. Vasospasm arises primarily in the region of the aneurysm. The intensity correlates well with the quantity of blood in the subarachnoid space. The vasospasm can progress with a time-lag from one arterial system to another.

The ischemic lesions are not only due to the vasospasm, but also to an increase in plasma viscosity. Our investigations have shown that the reason for this hemorrheologic deterioration is an increase in the fibrinogen concentration which correlates well with the severity of the clinical course. Thus, the prevention of ischemic lesions requires monitoring of the plasma viscosity. The treatment includes hypertensive therapy or hemodilution. We prefer hemodilution with hydroxyethylstarch. The plasma expander should not increase plasma viscosity or induce coagulation disturbances. Hemodilution seems to allow again the use of antifibrinolytic agents.

Hypertensive crises are due to an increase in ICP and to the disturbance of the autonomic nervous system. The continuous beta-blockade with metoprolol and the ICP reduction by glycerol can improve the clinical outcome of the patients.

Monitoring of the autonomic nervous system shows an increase in plasma renin-angiotensin-aldosterone activity and of catecholamine blood levels. The consequences include myocardial microinfarctions, electrocardiographic changes, and an increase in blood pressure. The main reason is a sympathetic overactivity, which can be successfully treated with the beta-blocker metoprolol.

MONITORING WITH TRANSCRANIAL DOPPLER

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Transcranial Doppler sonography (TCD) is a new approach to studying cerebral hemodynamics in the intracranial arteries. Since continuous noninvasive monitoring of middle cerebral artery blood velocity is possible, TCD seems ideal for intraoperative cerebrovascular monitoring.

The TCD has to be positioned at the transtemporal window before induction of general anesthesia. Because of technical problems (missing temporal window, obstacles during operation), only 71% of the patients undergoing extracerebral vascular surgery are subject to a full investigation [1]. The monitoring of the velocity of the middle cerebral artery is useful in patients with carotid surgery, cardiopulmonary bypass, or other cardiac surgery.

When one compares electroencephalographic (EEG) and evoked potential data with TCD, one can see that a decreased TCD flow accompanies deterioration of EEG and evoked potentials [2].

REFERENCES

1. Krupski WC, Bass A, Otis SM, et al. Intraoperative transcranial doppler. In: Proceedings of the 3rd International Symposium on Intracranial Hemodynamics, 1989
2. Lorenz H, Gabb MR, Dorfmutter G, et al. Intraoperative monitoring with TCD, EEG and evoked potentials in extracranial cerebrovascular disease. In: Proceedings of the 3rd International Symposium on Intracranial Hemodynamics, 1989

MAGNETIC RESONANCE AND SINGLE PHOTON EMISSION COMPUTED TOMOGRAPHY OF TRAUMATIC BRAIN DAMAGE: IMPLICATIONS FOR EARLY AND LATE STAGES OF HEAD INJURY

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Developments in neuroimaging have enabled new information to be gained about patterns of traumatic brain damage and their early and late functional implications.

The extreme sensitivity of magnetic resonance imaging (MRI) to structural damage shows patterns of lesions undetected by computed tomography. The depth of involvement of the neural axis that is demonstrated by MRI most closely reflects the severity of the injury. Thus, deeper lesions correlate with more profound and persistent impairment of consciousness at the acute stage; this is in accord with the centripetal shearing mechanism and with the pattern of diffusion axonal injury that occurs in fatal cases. Similarly, in survivors, the depth of involvement demonstrated by MRI correlates strongly with the degree of persisting disability and neuropsychologic abnormality.

Cortical MRI lesions do not seem to be important in determining consciousness at the acute stage. Similarly, it is not clear how far different mental sequelae can be explained by differential injuries in different cortical areas (e.g., right versus left, frontal versus temporal, anterior versus posterior). One reason for this is the frequency with which multiple areas are involved in the same patient; indeed, characteristic constellations of lesions, injuries in multiple sites commonly occurring together, can be recognized. This limits the feasibility of precisely mapping the different aspects of the mental sequelae of head injury.

Tomographic imaging of the distribution of isotope tracers, using single photon emission computed tomography (SPECT), has great potential in the acute and late stage after injury. During the acute stage, imaging of tracers of local cerebral blood flow shows complex patterns of focal ischemia, especially around intracranial hematomas, and also the occurrence in discrete areas of hyperemia. During the late stage, local cerebral blood flow distribution provides an index of function-related metabolism and can show patterns of abnormality at local cerebral function, not predicted from structural imaging.

With both MRI and SPECT, studies can be performed to investigate pathophysiology of injury, for example, changes in blood-brain barrier. Thus, these investigations can be used to assess the principles on which head injury management is based.

LONG-TIME MONITORING—OPTIONS TO USE ON PATIENTS IN NEUROLOGIC INTENSIVE CARE UNITS

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Evoked potentials have become standard monitors in many neurologic intensive care unit patients. Until now, multimodality was possible only in follow-up examinations. A first experience with a new system continuously monitoring 12 neurophysiologic and clinical variables at the bedside is reported. It consists of an IBM computer and various stimulation units. Electroencephalographic (EEG) activity (Cz-A1/Cz-A2), median nerve somatosensory evoked potentials (N14, N20), central conduction time, brainstem auditory evoked potentials, and I–V interpeak latency are recorded. Additionally, EEG frequency bands, heart rate, heart rate variability, intracranial pressure, body temperature, end-expiratory P_{CO_2}, blood pressure, and transcutaneously measured oxygenation (Critikon Oxyshuttle) can be monitored.

To date, we have monitored 33 patients (11 with intracerebral hemorrhage, 9 with brain infarction, 4 with subarachnoid hemorrhage, and 9 others) for up to 173 hours (mean, 41 hours).

The long-time monitoring improves observation and treatment of intensive care unit patients: deterioration in patient condition is recognized earlier, the system gives diagnostic

and therapeutic support (e.g., in patients suffering increased intracranial pressure, timing for hyperosmotic medication or neurosurgery is improved), the moment of brain death is observed more precisely, and the prediction of the patient's outcome is improved.

NEUROPHYSIOLOGIC AND NEUROPSYCHOLOGIC METHODS AS COMPLEMENTARY MEASURES IN NEUROMONITORING

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The monitoring of brain electrical activity provides important information about the functional state of the central nervous system. The recording of the spontaneous electroencephalogram (EEG) and the sensory evoked potential (EP) has been proven to be a sensitive method to assess the transmission of information from sensory receptors via different levels of neuronal processing to cortical integration. Therefore, alterations of brain electrical patterns can be used as an index of changes of cerebral information processing due to different levels of consciousness. So far, the application of EEG and EP recording is restricted to the monitoring of vital functions. The use of neuromonitoring to study higher cortical functions is still in its beginning. It is of greatest interest, however, to understand different EP and EEG patterns in their relationship to basic psychologic processes.

In the last years, the different aspects of attention and arousal as basic mechanisms of cerebral information processing and their neuronal correlates have been intensively studied. One reason is that deficits of attention and arousal have been proven to be a main symptom in patients suffering from severe head injury which results both in focal and diffuse brain damage. The understanding of the neuronal mechanisms that underly these deficits might provide an important insight into brain behavior relationships. In this presentation, the authors presented neuropsychologic and neurophysiologic methods which aim at determining deficits in attention and at disclosing neuronal mechanisms. The application of psychologic measurements and the role of event-related potentials as indices of attention-related processes in different levels of consciousness were also outlined.

OBJECTIVE ANALYSIS IN SUBARACHNOID HEMORRHAGE—IS IT BETTER THAN THE VIEW FROM THE END OF THE BED?

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Deterioration following subarachnoid hemorrhage or surgery for intracranial aneurysm can arise from rebleeding, the development of communicating hydrocephalus, operative complications, infection, or vasospasm [1]. Differentiating the exact nature of deterioration, therefore, has become important. However, few aneurysm surgeons doubt that the presence of vasospasm in general relates to grade and outcome, and it has also been demonstrated that vasospasm can occur within 24 hours of hemorrhage and can last for 1 to 4 weeks [2,3]. Of course, cerebral angiography remains the gold standard for the detection of vasospasm. However, many neurosurgeons have not been prepared to submit patients to recurrent angiograms, which in themselves are not without risk, and bedside methods of assessment to add to clinical judgment have therefore become important. Over the years, we have performed extensive studies on three of these bedside methods: assessment of a somatosensory evoked response, assessment of hemispheral blood flow, and assessment of Doppler cerebral blood flow (CBF) velocity. Together, these methods add objective criteria to the other available means of assessment of the condition of an aneurysm patient.

Of the evoked potentials in clinical practice, somatosensory evoked potentials have so far proved most useful for the detection of cerebral ischemia, our key measurement being that of central conduction time (CCT) [4]. As a premonitor of ischemia, the technique, being an episodic one, was not very successful. We did find, however, that the technique was useful in relation to the prediction of outcome.

Most systems for measuring CBF remain large, remote from the ward situation, and unsuitable for the repetitive study of critically ill patients [5]. Techniques of analysis, particularly the modifications by Obrist of a two-compartmental exponential model with the analysis of intravenous administration of isotope, have permitted the rapid analysis of CBF, and in the last few years, advances in electronics and microprocessors have enabled the development of a portable self-contained compact machine that can be easily moved to the patient's bedside [6–8]. Used on a regular basis in the day-to-day management of patients, this machine has permitted recurrent CBF measurements in the intensive care unit, on the ward, in the operating theater, and in the recovery room.

The modification of Doppler ultrasound by Aaslid and colleagues permitted the transcranial measurement of the velocity of CBF [9]. This simple bedside technique can therefore be used to assess the probability of a patient developing a spasm. Other investigators have shown that changes in DFV profile postoperatively may be of considerable value in following the course of such vasospasm, but we have found it somewhat disappointing in this regard.

Angiography can never be superseded; computed tomography scans with the assessment of the density and distribution of subarachnoid blood have been shown of considerable value in relation to spasm; and the fundamental analysis, the view from the foot of the bed by an experienced clinician, can therefore be expanded in a variety of collateral ways, all of which will lead to fresh and increased understanding of the vexing question of vasospasm over the next few years.

REFERENCES

1. Ecker A, Riemenschneider PA. Arteriographic demonstration of spasm of the intracranial arteries with special reference to saccular arterial aneurysms. J Neurosurg 1951;8: 660–667
2. Loach AB, De Azevedo-Filho HRC. Some observations in the microneurosurgical treatment of intracranial aneurysms. Acta Neurochir (Wien) 1976;35:97–103
3. Weir B, Grace M, Hansen J, et al. Time course of vasospasm in man. J Neurosurg 1978;48:173–178
4. Hume AL, Cant BR. Conduction time in central somatosensory pathways in man. Electroencephalogr Clin Neurophysiol 1978;45:361–375
5. Ingvar DH, Lassen NA. Quantitative determination of regional cerebral blood flow in man. Lancet 1961;2:806–807
6. Agnoli A, Prencipe M, Priori AM, et al. Measurements of

rCBF by intravenous injection of 133Xe: a comparative study with intraarterial injection methods. In: Brock M, Fieschi C, Ingvar DH, et al, eds. Cerebral blood flow. Berlin, Springer-Verlag, 1969:31–34
7. Austin G, Horn N, Rouhe S, et al. Description and early results of intravenous radioisotope technique for measuring regional cerebral blood flow in man. Eur Neurol 1972;8: 43–51
8. Thomas DJ, Zilha E, Redmond S, et al. An intravenous xenon-133 clearance technique for measuring cerebral blood flow. J Neurol Sci 1979;40:53–63
9. Aaslid R, Huber P, Nornes H. Evaluation of cerebrovascular spasm with transcranial Doppler ultrasound. J Neurosurg 1984;60:37–41

THE FUTURE OF BRAIN MONITORING

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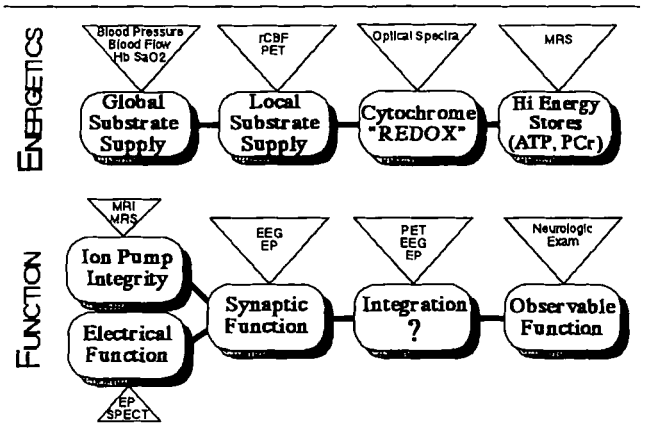
Adequate and appropriate monitoring of the central nervous system (CNS) in the operating room and intensive care unit is a goal that has fascinated investigators for six decades. Various modalities have enjoyed episodic enthusiastic use, but, overall, this goal remains elusive, with no current modality providing truly adequate data.

The future of CNS monitoring would be well served by innovators who look beyond the detection of isolated physiologic variables to the development of systems with clinically useful goals. I present two quasi-independent clinical goals for discussion. First is the development of a monitoring system that can continuously assess cerebral "well-being," where well-being is defined as a state from which complete recovery to normal function can quickly occur. Ideally, such a monitor would be able to assess reversibility and to distinguish, for example, the electrocerebral silence of barbiturate coma from that associated with brain death. The second goal of a clinically useful system would be to assess the "depth of anesthesia," but the lack of an all-encompassing definition of depth of anesthesia makes this a difficult task. Anesthesia actually consists of at least five potentially independent phenomena: analgesia, amnesia, sedation, decreased autonomic reflex activity, and muscle relaxation. Of these, only muscle relaxation can be monitored directly; the remaining components can be assessed only by observation of epiphenomena because there are no reliable, real-time indicators for them.

Cardiac monitoring has become routine in acute care settings because it allows detection of events clearly related to patient outcome. Current practice in acute care cardiac monitoring focuses on aspects of the metabolic supply versus demand ratio and detailed analysis of mechanical function.

Although we have no metrics for cerebral metabolic demand or function, we can provide a comparable model of energetics and function, as illustrated in the Figure. This model crudely subdivides the physiologic processes of CNS energy metabolism and function into discrete processes. Illustrated alongside are monitoring modalities which are specifically sensitive to these processes and applicable to clinical monitoring or research. Each of these modalities has advantages and limitations. In light of our current appreciation of the heterogeneity of brain activity and function, perhaps the greatest limitation shared by most monitors is that of spatial resolution. It is reasonable to expect that adjacent neurons may have differing metabolism, and glia different still, yet our best



Summary of potential modes for monitoring energetics and function of the brain.

monitors average the output over hundreds of thousands of cells.

Several interesting new technologies for CNS monitoring and research are now in development. Although difficult to view as clinical monitoring tools, magnetic resonance spectroscopy and magnetic resonance imaging continue their rapid pace of development. Magnetic resonance spectroscopy can detect and quantify intracellular high-energy phosphate compounds (using 31P), lactate (1H), intracellular pH, transmembrane sodium fluxes (23Na), and regional blood flow (19F). Magnetic resonance imaging can image a variety of contrast agents with high spatial (<0.1 mm) and temporal (0.05 s) resolution, and proton diffusion imaging can now detect cytotoxic cerebral edema within minutes of injury. Albunex, a recently developed contrast agent for ultrasonic imaging, may provide an inexpensive means of assessing regional cerebral blood flow intraoperatively, in real-time. Multichannel optical spectroscopy uses changes in reflectance, absorption, and fluorescence to quantify hemoglobin oxygen saturation, tissue blood volume, mitochondrial redox state (cytochrome aa3, NADH), and, with dye probes, intracellular calcium. Signal processing techniques applied to the analysis of the electroencephalogram and the evoked potential response have simplified interpretation of some aspects of this electrical activity and have expanded our ability to discern spatial relationships using topographic mapping of many electrodes.

Simultaneous application of combinations of these new monitoring modalities designed to achieve the appropriate clinical monitoring goals probably represents the most fruitful path we can pursue for brain monitoring. The evolution of CNS monitors must strive to meet these clinical goals if the clinician is to be enticed into routine use of such monitors.

THE USE OF SOMATOSENSORY EVOKED RESPONSES IN CAROTID SURGERY

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The purpose of this work was to verify the usefulness of somatosensory evoked potentials (SEPs) in detecting cerebral ischemia and the need for a shunt during carotid endarterectomy (CEA).

Somatosensory evoked potentials were recorded under general isoflurane anesthesia in 16 patients undergoing CEA. Detailed neurologic examination was carried out in the days preceding the operation and was repeated immediately after a patient's awakening from anesthesia. The median nerve was stimulated at one wrist before induction of anesthesia and during surgical intervention. Recordings were made from electrodes located at the 7th cervical spinous process and over contralateral cortex; the forehead lead was used for reference. Before arteriotomy, the cerebral blood flow was indirectly evaluated by means of intraoperative stump pressure measurement. Mean and standard deviation of preclamping and postclamping values were calculated. The statistical significance of data was assessed by Student t test for paired data.

The N13 and N20 waves never disappeared. The N20 latency values showed a variation wider than 1 msec in 12 cases; central conduction time values showed the same variations in all patients. An N20 amplitude variation larger than 50% of maximum value was found in 10 cases. These modifications occurred with no correlation to carotid clamping, often being related to arterial pressure changes. No significant differences between preclamping and postclamping mean values were observed in all indices ($P < 0.05$). Pressures ranged between 40 and 111 mm Hg ($M = 62 + 23$). Neurologic deficits were never observed in our patients.

The variations observed during preclamping and postclamping showed limitations in the use of SEPs during CEA. These variations could be related to changes in arterial pressure. We have demonstrated in a previous study the possibility of using SEP monitoring during isoflurane anesthesia. However, the absence of significant differences between preclamping and postclamping mean values, with no stroke in our cases, does not rule out the possibility of using SEPs during CEA in the presence of hemodynamic stability.

ADJUSTED SURGICAL AND ANESTHETIC MANAGEMENT OF CAROTID ENDARTERECTOMY BY MEANS OF SOMATOSENSORY EVOKED POTENTIAL

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Reconstructive carotid surgery can be justified only by a low rate of perioperative neurologic deficits. To avoid complications, careful selection of cases, meticulous surgical technique, and intraoperative assessment of cerebral perfusion are necessary. The latter should reliably identify patients with inadequate collateral perfusion and impending cerebral damage during carotid artery clamping. These patients benefit from cerebral protective measures (for example, bypass shunt or induced hypertension), which have their own complications (for example, embolization or myocardial infarction) and should therefore be used only in selected cases.

During 378 carotid surgical procedures using general anesthesia, somatosensory evoked potentials (SEPs) were recorded for cerebral monitoring from a cervical (C2-Fz) and parietal (C3′/C4′-Fz) electrode above the ipsilateral hemisphere in response to stimulation of the opposite median nerve. To evaluate the reliability of SEP monitoring, in a preliminary study (n = 150 patients) no cerebral protective techniques were used and the surgeon had no knowledge of the SEP results during the clamping period. Owing to a good correlation between intraoperative SEP findings and neurologic outcome in the preliminary study (a serialized study of 228 patients), we tested the effectiveness of an indwelling shunt when the cortical SEP became absent.

In the preliminary study, complete flattening of the N20/P25 complex persisted in 8 cases during the clamping period. Postoperatively, 2 patients had no neurologic events, 5 showed transient ischemic attacks (TIAs), and 1 developed a severe stroke. In the following study, 9 patients demonstrated a complete loss of the postcentral SEP components after carotid clamping. With shunt insertion, SEP returned to normal in 7 cases. Six of these patients had no neurologic deficit, while 1 experienced a transient neurologic failure. In 1 case, the cortical amplitude reappeared incompletely with shunt placement; this patient developed a TIA. In another case, the cortical amplitude did not recover due to an insufficient shunting device; this patient developed a mild stroke. During 361 operations, the cortical SEP responses were reproducible after carotid clamping. Postoperatively, neurologic examination was normal in 356 cases. Three patients showed hemiparesis immediately, while 2 patients developed hemiparesis 2 hours after extubation. However, since either a local thrombosis was found at reoperation or angiography revealed a complete occlusion of the reconstructed vessel in these patients, it can be assumed that neurologic sequelae were caused by embolization and not by ischemia due to carotid cross-clamping.

Our results confirm a high sensitivity and specificity of SEP monitoring in the early detection of a clinically relevant cerebral ischemia after carotid clamping. Cerebral protective measures can be applied, adjusted to the individual risk and benefit. A selective shunt placement in the absence of the cortical SEP avoids neurologic deficits in a high percentage; the sufficiency of the shunting volume can be verified. Pathophysiologic mechanisms of neurologic deficits are revealed. Therefore, SEP data may be helpful in decision-making for reoperation. As a considerable advantage, endarterectomies can be done without a shunt or haste if there is a cortical somatosensory response. These findings should help to reduce the rate of perioperative complications.

REFERENCES

1. De Vleeschauwer Ph, Horsch S, Matamoros R. Monitoring of somatosensory evoked potentials in carotid surgery: results, usefulness, and limitations of the method. Ann Vasc Surg 1988;2:63–68
2. Gigli GL, Coramia M, Marciani MG, et al. Monitoring of subcortical and cortical somatosensory evoked potentials during carotid endarterectomy: comparison with stump pressure levels. Electroencephalogr Clin Neurophysiol 1987;68:424–432
3. Zurbruegg HR, Seilser RW, Grolimund P, Mattle H. Morbidity and mortality of carotid endarterectomy: a literature review of the results reported in the last 10 years. Acta Neurochir 1987;84:3–12

EXPERIENCE WITH SOMATOSENSORY EVOKED POTENTIAL MONITORING DURING CAROTID ENDARTERECTOMY

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The last 12 cases from a series of 240 carotid endarterectomies at the bifurcation were performed with somatosensory evoked potential (SEP) monitoring. Software was developed to allow

sequential SEP recording with fully automatic evaluation and statistical testing of differences between subsequent records. The results were compressed in a trend diagram, displayed on a monitor, and intraoperatively shown to the surgeon. Every 90 seconds, an update of the diagram occurred.

The introduction of monitoring changed our policy regarding the use of an internal bypass. Regularly done before, its application was now guided by changes of the SEPs. It was found that in the last 12 cases, no bypass was necessary, even in some cases with collateral stenosis or obliteration of the internal carotid artery. In one case, the postoperative control angiogram showed a secondary obliteration of the operated region, the patient remaining free of deficits. In another case, however, a progressive hemiparesis developed, with a delay of 8 hours after the surgical procedure. This patient had marked vessel disease with further stenosis at the petrosal part of the endarterectomized carotid artery; we assume that this caused a delayed embolism.

We conclude that SEP monitoring is a reliable indicator of cerebral ischemia during carotid artery surgery, and that the use of our software allows a very rapid relay of information to the surgeon. Complications, however, may arise from events that occur after the endarterectomy itself, and, naturally, these cases cannot be detected by intraoperative monitoring.

INTRAOPERATIVE ELECTROENCEPHALOGRAPHIC AND SOMATOSENSORY EVOKED POTENTIAL MONITORING IN EXTRA-INTRACRANIAL HIGH-FLOW BYPASS PROCEDURES VIA VENOUS INTERPOSITION

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High-flow bypass operations via venous interposition to deep-seated proximal branches of the middle cerebral artery are accompanied by the danger of intraoperative ischemic damage during the clamping time of the recipient vessel, as well as the potential flow redistribution due to the immediate high flow once the bypass is opened (up to more than 200 ml/min). During trial clamping, the use of electroencephalographic (EEG) and somatosensory evoked potentials (SSEP) can help decide which of the available vessels is the safest for anastomosis.

Of a total of 40 patients, 38 underwent an extra-intracranial bypass via venous transplant for cerebral revascularization. Intraoperative electrophysiologic monitoring included EEG spectral analysis (25 patients), bilateral SSEP monitoring (10 patients), and both methods (three patients). The following evoked responses were considered pathologic:

With SSEP: an increase in central conduction time N13 to N20 over 8 msec and/or a decrease in N20 amplitude of more than 50%; with the EEG: lateralized slow wave activity (if not preexistent), and generalized slowing with lateralized slow-wave activity.

In all patients monitored with intraoperative EEG frequency analysis, no changes considered as pathologic were seen. However, symmetric bilateral changes, such as an increase or decrease in general activity, were often observed due to varying concentrations of volatile anesthetics and the administration of drugs such as thiopental for cerebral protection before temporary brain vessel occlusion. In contrast, the SSEP recordings with the N13 to N20/P25 complex remained stable under different conditions of anesthesia, whereas the later components also seemed very sensitive to drug influences. In all 13 patients with continuous intraoperative SSEP monitoring, no pathologic changes were seen. After bypass was established in 2 patients with giant aneurysms, the internal carotid artery had to be occluded permanently for management of the aneurysm. In both of these patients, no changes in central conduction time or amplitudes were noted.

Extra-intracranial bypasses with vein graft interposition permit an immediate high flow to proximal cerebral vessels for revascularization. Since most of these patients already had severe hemodynamic disturbances preoperatively, this kind of anastomosis could have risks similar to those seen with carotid endarterectomy. Electrophysiologic monitoring should therefore be performed during the surgical procedure. The SSEP recordings seem to be more stable with regard to anesthesia and drug administration, particularly since we first try to keep systemic blood pressure raised until the anastomosis is opened, and then decrease it to values under 140 mm Hg systolic to avoid a break-through phenomenon. Especially in patients with giant or infraclinoidal aneurysms, intraoperative SSEP and EEG findings can aid in the decision of temporary or permanent occlusion of skull base vessels.

NEUROPHYSIOLOGIC MONITORING IN CAROTID ARTERY SURGERY: A COMPARISON OF SOMATOSENSORY EVOKED RESPONSES AND TRANSCRANIAL DOPPLER ULTRASOUND

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Using somatosensory evoked potentials (SEPs) after median nerve stimulation, cerebral function impairment after clamping of the internal carotid artery (ICA) can be detected with a high amount of sensitivity and specificity. Moreover, prognostic information concerning the patient's neurologic outcome can be given [1]. Transcranial Doppler sonography (TCD) allows an estimation of cerebral perfusion by noninvasively measuring blood flow velocities in basal cerebral arteries. Our prospective study was designed to compare electrophysiologic findings (SEP) with cerebral hemodynamics (TCD) before, during, and after clamping of the ICA.

Ninety-seven patients undergoing 103 carotid operations were studied (TIA, 43; RIND, 9; cerebral infarction, 24; others, 21). The SEPs were recorded from the scalp (C3'-Fz or C4'-Fz) and from the second spinal process (C2-Fz). The amplitude of the primary cortical evoked response N20/P25 was measured peak-to-peak. Central conduction time (CCT) was calculated as the difference between the first negative cortical (N20) and cervical (N14) peak. Transcranial Doppler sonography was performed by a pulsed 2-MHz Doppler device. The mean blood flow velocity in the middle cerebral artery (Vm-MCA) was recorded transtemporally with the depth set at 45 to 55 mm. The TCD and SEP variables were recorded prior to and immediately after carotid clamping, in short intervals during the clamping period, and after declamping. Critical SEP alterations after clamping (N20P25 $<$ 50% and/or CCT $>$ 20% compared with preclamping values) led to selective temporary intraluminal shunting. Vm-MCA reduction greater than 60% after carotid clamping was compared with critical SEP findings by χ^2 test.

While SEP was always able to be recorded, combined SEP and TCD monitoring was possible in only 78 of 97 cases owing to technical or anatomic reasons. After carotid clamping, 11 patients showed critical SEP alterations, among whom 6 could also be monitored by TCD. Vm-MCA reduction greater than 60% in these patients was significantly related to

critical SEP alterations (χ^2 test, $P < 0.001$). Another 5 patients showed critical TCD changes without relevant SEP alterations. One special case with critical SEP changes had only a minor Vm-MCA reduction (33%). In the remaining 66 patients, a Vm-MCA reduction less than 60% was always tolerated without critical SEP alterations. Four patients had new transient neurologic deficits postoperatively. During surgery, all had critical TCD and SEP findings.

In conclusion, we found that combined SEP and TCD monitoring during carotid artery surgery allows rapid and noninvasive "input-output" evaluation of cerebral hemodynamics; TCD gives an on-line estimation of cerebral perfusion after carotid clamping and shunt insertion, even before functional impairment is reflected by critical SEP changes; and our method is helpful in detecting those patients who will profit from temporary shunting after clamping of the ICA.

REFERENCE

1. Russ W, et al. Thorac Cardiovasc Surg 1985;33:392–396

INFLUENCE OF THE STIMULATION PERIOD ON THE LATENCIES OF CO_2 EVOKED PAIN POTENTIALS

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The application of CO_2 on the nasal mucosa is a new method of experimental pain stimulation, adding to the hitherto usual procedures of dental pulp stimulation, CO_2 lasers, electrocutaneous pain stimulation, and other procedures. A short-duration shooting pain develops at the application site [1]. This CO_2 evoked potential is characterized by the absence of any electrical stimulation artifacts. In the literature, variably long periods of stimulation have been described. In our experience, we found that, despite constant CO_2 concentration, subjective pain sensation increases with an increased stimulation period and that maximal pain is delayed. Our study was intended to check whether a variation in the period of stimulation results in a shift of the evoked potential (EP) latencies.

We studied 6 volunteers, with four experiments being undertaken in each series. All volunteers gave their written agreement to participate and were entitled to discontinue the experiment at any time.

Stimulation took place with a CO_2 stimulator (Anamon) developed by Dräger. Via a valve mechanism, the CO_2 was admixed to a continuous air flow in exact time intervals. The gas mixture was fed to the nasal mucosa via a hose system, passing through a respiratory gas moistener. To avoid tactile stimuli, temperature and moistening of the gas flow were controlled automatically. The CO_2 stimuli were applied to the mucosa of the right nostril. Apart from the period of stimulation (50, 100, and 500 msec), all settings of the stimulator were kept constant: interstimulus intervals, 10 s; CO_2 concentration per stimulus, 65 vol% CO_2; and total flow of the gas, independent of the CO_2 concentration, 9 L/min. Strict mouth breathing was required to prevent breathing against the gas mixture flow.

A "NeuroScope" (Dantec) was used to record the responses. Evoked potential derivation took place with Ag electrodes at the following derivation points: Cz, Fz, Pz, C3, and C4/A1. The base electrode was set at Fpz.

Derivation Cz/A1: Mean Values and Standard Deviations of the Evoked Potential Latency Periods in Milliseconds (N = 6)

Stimulus Period	50 msec	100 msec	500 msec
N1			
Mean	128	128	122
SD	5.78	9.12	12.1
P1			
Mean	212	198	215
SD	8.00	13.7	18.5
N2			
Mean	260	273	287
SD	43.4	64.4	89.1
P2			
Mean	355	386	361
SD	6.55	64.1	46.7

To be able to recognize artifacts due to eye movements, a control electrode was applied paraorbitally on the right. The basic settings of the "NeuroScope" were the same in all experiments: filter, 1 to 120 Hz; prestimulus time, 25 msec; poststimulus time, 2,000 msec. Recording was undertaken by averaging 50 stimuli.

Since the activity at the derivation locations that we used is similar to the vertex potential, we limit ourselves to the presentation of the Cz-derivation.

Despite a change in the stimulation period, we were unable to observe any significant differences between the individual latencies (Table). With constant CO_2 concentration, the overall amplitudes of the vertex potentials did not demonstrate any difference related to stimulus duration.

The latency potentials observed agree with data in the literature [2]. We suggest that the lack of latency shift is due to the following: The beginning of CO_2 stimulation seems to be decisive for the cortical response. Therefore, any stimulation beyond the EP latency will not cause any alteration in amplitude and latency. The assumed indirect increase in CO_2 concentration due to the increased period of stimulation could not be proven either by latency shifts or amplitude increases.

REFERENCES

1. Kobal G. Pain-related electrical potentials of the human nasal mucosa elicited by chemical stimulation. Pain 1985; 22:151–163
2. Kobal G, Hummel C. Cerebral evoked potentials elicited by chemical stimulation of the human olfactory and respiratory nasal mucosa. Electroencephalogr Clin Neurophysiol 1988;71:241–250

BRAINSTEM AUDITORY EVOKED POTENTIALS IN NEONATES WITH CHIARI II MALFORMATION IN RELATION TO VENTRICULOPERITONEAL SHUNTING

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The recording of brainstem auditory evoked potentials (BAEPs) is a noninvasive electrophysiologic measurement of

the functional integrity of the brainstem. To determine the effect of ventriculoperitoneal shunting on brainstem function in neonates with Chiari II malformation and hydrocephalus, we compared the difference between BAEPs recorded in such patients before and after surgery.

The BAEPs were recorded from the vertex electrode with reference to the ipsilateral mastoid in 15 full-term neonates with Chiari II malformation and hydrocephalus. Click stimuli of 0.1 msec were presented at 7.29 Hz. Peak latencies for waves I and V were measured and interpeak latency (IPL) I–V was calculated. The second BAEP recording after surgery followed the first by a mean of 6 days (range, 2–15 days). Comparison of the BAEPs before and after the shunting procedure showed two types of responses. In the first type (6 neonates), the initially absent wave V appeared after surgery. In the second (9 neonates), we measured a decrease in absolute wave V latency (mean, 1.63 msec), absolute wave I latency (mean decrease, 0.19 msec), and I–V IPL (mean decrease, 1.51 msec). Repeated-measure analyses of variance were used to evaluate changes in absolute peak latencies and I–V IPL between the two recordings. The analysis was significant at less than 0.01 level of probability for wave V and I–V IPL.

The results indicate that the brainstem function in neonates with Chiari II malformation and hydrocephalus is improved after the shunting procedure.

DIGITAL ANALYSIS OF AUDITORY-EVOKED POTENTIALS AS FURTHER APPROACH TO ANESTHETIC DEPTH

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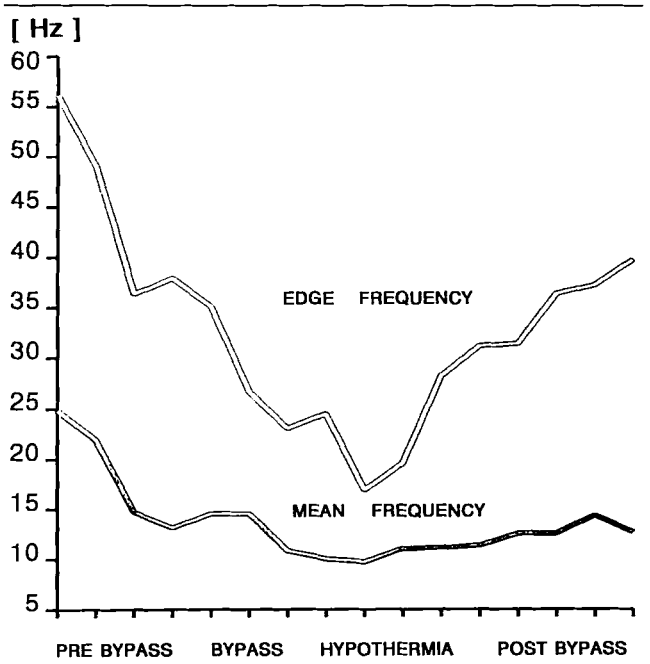
The ability to induce unconsciousness and a state of physical unresponsiveness to surgical stimuli is an important characteristic of an anesthetic agent. Unconsciousness is difficult to guarantee, and the problem of awareness becomes paramount. Therefore, objective methods are necessary. Perhaps the auditory evoked potentials (AEPs) could provide a possible indicator of anesthetic depth. We therefore used fast Fourier transformation to analyze and compare the AEPs produced by a balanced anesthesia. Using a Nicolet Pathfinder I, AEPs were recorded from 20 patients undergoing open heart surgery as follows: impulse, binaural click (70 dB above hearing level, 9 and 7 Hz); and derivation, Cz (pos), A1/A2 (neg), filter, 5 to 1,000 Hz, rate, 250. To achieve a result from 2.5 Hz for spectral analysis, the timebase of 400 msec was lengthened and stimulated fourfold. The mean frequency and edge frequency were derived from the spectral analysis. The results can be seen in the Figure. With the on-line registration of AEPs and the fast Fourier transformation, we tried to find additional variables that would yield information relating to the depth of anesthesia.



Edge and mean frequencies from AEPs as a function of various events during cardiac surgery.

NEUROPHYSIOLOGIC MONITORING BY MEANS OF EVOKED POTENTIALS DURING CERVICAL SPINE SURGERY

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Notwithstanding more recent advances in neurosurgery, cervical spine surgery still poses high risks of damage to the spinal cord and nerve roots, both for direct surgical trauma and possibly for ischemia in the vertebrobasilar territory. Therefore, it seems of particular interest to monitor spinal cord, nerve roots, and brainstem intraoperatively.

Somatosensory evoked potentials (SSEPs) and brainstem evoked potentials (BAEPs) were recorded intraoperatively in 68 patients who underwent surgical procedures on the cervical spine for different diseases. The SSEPs were recorded at lumbar, Erb's point, and cervical and cortical levels on upper and lower limb bilateral stimulations. The spinal cord conduction velocity (derived from the lumbar-to-cervical conduction time), the central conduction time (which is the conduction time between high cervical level to cortex), the morphology, and the amplitude of the cortical waves were evaluated. The BAEPs were recorded on single ear stimulations and were repeated on each side to assess brainstem function.

Generally, SSEPs were severely deranged during laminectomy or retractor positioning on spinal cord or intersomatic distractors placement. In 55 cases, SSEPs recovered at the end of the procedure and the patients did not suffer a postoperative worsening. In the remaining patients, in whom intraoperative SSEPs did not recover, a neurologic worsening or, at least, no improvement was observed. The BAEPs were affected mainly during patient positioning, suggesting that this maneuver would be critical for vertebral blood inflow; moreover, no permanent BAEP alterations were observed. Intraoperative SSEP monitoring proved to be more reliable when a posterior approach was performed, while, in the case of an anterior approach, we think that motor evoked potential monitoring would be more useful, since it is able to assess corticospinal pathways function.

BRAIN MAPPING OF ELECTROENCEPHALOGRAPHY DURING INDUCTION OF ANESTHESIA WITH PROPOFOL

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Previous studies with propofol used only a few electroencephalography (EEG) channels [1]. In this study, we wanted to describe the topographic EEG activity distribution [2] during induction of anesthesia with propofol.

Propofol, 2.5 mg/kg body weight, was administered to 10 patients who had not received any preanesthetic medication (7 men and 3 women scheduled for lumbar disc repair; 49.1 ± 14.5 years of age; body weight, 72.5 ± 8.5 kg; injection time, 60 s). A 19-channel EEG (international 10/20 system) with filters set to 1 and 30 Hz was recorded and stored using a Brain Atlas III (Bio-logic). Fast Fourier transformation of artifact-free, 2-second epochs was performed off-line. Mean value maps were compared statistically using the one-dimensional analysis of variance and the Scheffe test.

Patients were asleep within 69.8 ± 16.1 seconds after the start of propofol injection. The dominant frequency, defined as the frequency with the highest activity over the cortex, decreased from 9.3 ± 1.2 to 1.5 ± 0.4 Hz (mean values ± SD, n = 10, $P < 0.01$), while the activity increased simultaneously from 9.0 ± 6.7 to 37.4 ± 6.0 μV ($P < 0.01$). Maps of the different frequency bands during introduction of propofol anesthesia were presented.

Propofol, 2.5 mg/kg, provided a rapid induction of anesthesia. Similar to anesthetic induction with thiopental [3], a decrease of the dominant frequency from the alpha-band to the delta-band, an increase of the amplitude, and an anterior shift of the localization of the dominant frequency are regular and significant EEG features. Both studies indicate that EEG mapping during clinical anesthesia is feasible.

REFERENCES

1. Hartung E, Freye E. An open comparison of propofol and enflurane for prolonged abdominal operations. Anesthesia 1988;43:105
2. Maurer K, Dierks T. Topographic brain mapping of EEG and evoked potentials in psychiatry and neurology. EEG EMG 1987;18:4–12
3. Engelhardt W, Kullmann F, Dierks T, et al. Brain electrical activity mapping during induction of anesthesia with thiopentone. Deutscher Anästhesiekongress Bremen 1989

SEDATION OF POSTOPERATIVE VENTILATED PATIENTS WITH PROPOFOL OR MIDAZOLAM MONITORED BY ON-LINE ELECTROENCEPHALOGRAPHIC ANALYSIS

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Patients undergoing long operations may suffer from severe blood loss and decrease of body temperature. In addition, high dosages of narcotics and relaxants may require postoperative mechanical ventilation. In these cases, a well-managed sedation is necessary for the patient to tolerate the tube and ventilation during recovery from drug hangover and physical disturbances. In this study, we controlled the sedative effect of propofol and midazolam by on-line electroencephalographic (EEG) analysis.

According to a randomized scheme, 25 patients received propofol or midazolam for sedation after long-term intraabdominal or surface surgery. Induction of anesthesia was performed with thiopental followed by enflurane, opiates, and muscle relaxants. Postoperative sedation was started by a bolus (propofol 1 mg/kg body weight, midazolam 0.15 mg/kg body weight) and maintained by continuous injection via infusion pump. Both groups are described in Table 1. The state of sedation was scored by clinical aspects such as tolerance of tube and ventilator, response to acoustic and sensory stimulus, reflexes of eyelid, coughing, and chewing. Additionally, two-channel EEG recordings were performed using the leads C3-P3 and C4-P4 (10-20 system). The signal was analyzed on-line and stored by a laptop computer system (Toshiba T3200) using fast Fourier transformation for spectral analysis. Circulation variables were obtained by a Dinamap 1846SX and stored on hard disk together with the digitized EEG signal. The dosage of sedative was supported by the distribution of powerbands and median of the spectrum. The time between drug administration and the period of awakening after stopping sedative infusion was defined as time to awakening.

The EEG characteristics found in a previous study showing certain frequency distributions could be proven. Deepening, flattening, and steady state of sedation showed different EEG patterns between propofol and midazolam (Table 2). Propofol and midazolam also differ in time of awakening (see Table 1). Blood pressure and heart rate were stable under propofol sedation, whereas midazolam caused sudden drops of blood pressure and an increase of heart rate during awakening.

The EEG monitoring shows unwanted flattening and deepening of sedation with both propofol and midazolam. Sedation tailored to the patients' needs may be gained by using this method. Short time to awakening and decreased exposure

Table 1. Patients, Duration of Surgery, and Time for Awakening

Group	n	Sex F	Sex M	Age (yr)	Length (cm)	Weight (kg)	Duration of Surgery (min)	Time of Sedation (min)	Awakening (min)
Propofol	12	6	6	52.3 ± 12.2	168 ± 6.7	67.5 ± 8.1	313 ± 85.4	303.8 ± 128.7	77.1 ± 106.9
Midazolam	13	7	6	47.5 ± 17.0	167 ± 8.6	65.5 ± 11.3	380 ± 134.9	280.8 ± 104.9	362.62 ± 339.7

Table 2. Electroencephalographic Variables

	Distribution of Power (%)			
	Propofol		Midazolam	
	Steady State (%)	Flattening (%)	Steady State (%)	Flattening (%)
Delta	41.5	31.1	57	45
Theta	29.9	32.4	18	17
Alpha	22.9	27.9	14	20
Beta	5.9	9.5	11	18

to sedative drugs are the results of carefully applied EEG-supported sedation management. Nevertheless, there are still difficulties concerning automatic control of sedation because of EEG artifacts that cannot be perfectly recognized by a computer system. Concerning the administered drugs, propofol seems to be the better sedative for postoperative ventilation, whereas midazolam finds its place in long-term ventilation.

THE RELATIONSHIP BETWEEN THE LEVEL OF INTRAVENOUS-INHALATION ANESTHESIA AND ELECTROENCEPHALOGRAPHIC CHANGES

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Electroencephalographic (EEG) changes were observed during intravenous-inhalation anesthesia to pursue the effect of this anesthesia on EEG and to evaluate the clinical significance of EEG monitoring during this type of anesthesia.

Thirty patients (ASA physical status I-II, 17 males and 13 females aged 17 to 65 years) undergoing thoracic wall or abdominal operation were studied. Anesthesia was induced with diazepam, fentanyl, sodium thiopental, and succinylcholine. After endotracheal intubation, the patients were ventilated. Thirty patients were equally divided into two groups, each receiving enflurane or isoflurane. Fentanyl (0.2 mg/kg/hr) and *d*-tubocurarine (0.4 mg/kg/hr) were added during anesthesia. The EEG was monitored respectively on the day before operation, after inhalation of 2.0 mean alveolar concentration (MAC), 1.5 MAC, or 1.0 MAC enflurane or isoflurane for at least 20 minutes after the withdrawal of inhalation, and after endotracheal extubation. Blood pressure, pulse rate, EEG, and nasopharyngeal temperature were also monitored.

The frequency of the EEG was the most significant sign reflecting the level of intravenous-inhalation anesthesia; the next was the amplitude of the EEG. The EEG was much different before anesthesia; however, the changes of EEG tended to undergo the same process during anesthesia. Deep anesthesia significantly decreased the frequency of EEG, even resulted in "evoked depression." The amplitude of EEG commonly increased. Light anesthesia, on the other hand, increased the frequency of EEG and decreased its amplitude. The frequency of EEG, before consciousness, increased almost 200% compared with that before anesthesia.

During the same MAC state, the effects of enflurane and isoflurane on the EEG were nearly the same.

During the period of low-frequency high-amplitude of EEG, the effects of foreign unfavorable factors such as surgical stimulation and endotracheal suction on the human body were slight; the blood pressure and pulse rate remained normal. However, the blood pressure and pulse rate fluctuated violently during the period of high-frequency low-amplitude of EEG under the influence of foreign irritations.

Some patients had hypothermia during anesthesia, but no relationship was found between hypothermia and EEG changes.

This study demonstrated that the changes in the EEG had their own rules and were relatively constant, even during intravenous-inhalation anesthesia. During light anesthesia, EEG presented "activated" changes with high-frequency and low-amplitude waves. During deep anesthesia, EEG presented "depressed" changes with low-frequency and high-amplitude waves. When the frequency of EEG remained unchanged or a little slower than that before anesthesia, the level of anesthesia would be considered convenient.

During the "activated" period of EEG, the body is susceptible to the unfavorable irritation of foreign factors, and cardiovascular disturbances or other accidents may occur. Therefore, a convenient level of anesthesia should be maintained. Any kinds of unfavorable irritation should be avoided or diminished during light anesthesia or before the recovery of consciousness.

Electroencephalographic monitoring has many advantages, one of the most important being that it can supply correct, objective, and noninvasive information for the evaluation of anesthesia level, especially for balanced anesthesia, such as intravenous-inhalation anesthesia.

STUDY OF THE RELATIONSHIP BETWEEN POSTANESTHETIC SHIVERING AND ELECTROENCEPHALOGRAPHIC CHANGES

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Postanesthetic shivering has been observed following any type of general anesthesia and is most frequently associated with halothane. Risks to postoperative patients include an increase in oxygen consumption by up to 400%, which may be highly dangerous in patients with impaired respiratory or cardiovascular function. It may also cause failure of tendon or skin grafts. The mechanism of this phenomenon remains unknown, hampering prevention and treatment. The present study was designed to observe the relationship between postanesthetic shivering and electroencephalographic (EEG) changes to investigate the central mechanism causing postanesthetic shivering.

Thirty patients (ASA physical status I-II, 17 males and 13 females aged 17 to 65 years) undergoing thoracic wall or abdominal operation were studied. Anesthesia was induced with diazepam, fentanyl, sodium thiopental, and succinylcholine. After endotracheal intubation, the patients were ventilated. Thirty patients were equally divided into two groups, each receiving enflurane or isoflurane. Fentanyl (0.2 mg/kg/hr) and *d*-tubocurarine (0.4 mg/kg/hr) were added during anesthesia. Postanesthetic shivering and Babinski's and Chaddock's signs were observed continuously after the withdrawal of inhalation until the patient recovered consciousness. The EEG was monitored on the day before operation, during anesthesia, and after the withdrawal of inhalation. Blood pressure, pulse rate, ECG, and nasopharyngeal temperature were also monitored.

Postanesthetic shivering was observed in 7 patients (23.3%), 3 of them receiving enflurane, the others receiving

isoflurane. Positive Babinski's or Chaddock's signs were found in 8 patients (26.7%); of these, 6 had tremor. Postanesthetic shivering or abnormal nerve reflex occurred 10 to 20 minutes after the withdrawal of the agent and lasted for 5 to 15 minutes. The EEG presented waves of high-frequency low-amplitude during this period. The wave frequency of EEG reached 17 to 23 Hz, two times higher than before anesthesia and three times higher than that during anesthesia. Both shivering and abnormal nerve reflex disappeared after patients recovered from anesthesia. Meanwhile, the wave frequency of EEG decreased. Of the 77 patients with shivering, only 2 had slight hypothermia.

Our study demonstrated the following: (1) Postanesthetic shivering has no relation to the presence of hypothermia. (2) Some rules were found regarding the occurrence of postanesthetic shivering. It usually happened during the period in which the wave frequency of EEG reached its peak, but never when the frequency of EEG decreased. It seems that the mechanism of postanesthetic shivering is central.

(3) The high-frequency low-amplitude wave of EEG means that EEG activity remains in the "activated stage," suggesting that brain function was excited. For all these reasons, it may be inferred that a low or very low concentration of anesthetics can cause the excitation of brain function, resulting in the excess of action and hyperactive reflexes. Therefore, the tremor and abnormal nerve reflex may happen. The key to preventing and treating this complication may lie in the antagonism of central excitation.

ELECTROENCEPHALOGRAPHIC- AND EVOKED POTENTIAL–SUPPORTED PHARMACOLOGIC BRAIN PROTECTION

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In 1952, Weil-Malherbe described an increase of adenosine triphosphate (20%)—and creatine phosphate (36%)—content of cerebral stores following ether anesthesia. In 1973 through 1976, several investigators, comprehending unconsciousness as a reversible chemical lesion within the ascending reticular system, recommended metabolic depression by high-dose barbiturate in cases of hypoxia to an extent insufficient to abolish brain function. Further experiences make it necessary to look out for alternatives marked by an expanded spectrum of influence, including inhibition of lactacidosis, no reflow phenomena, and disturbed Ca^{2+} homeostasis, capable of membranous stabilization.

There were 70 patients, 18 to 74 years of age, with unconsciousness induced by trauma II/III (Toeniss and Loew, 1986) and 60 patients in postoperative and metabolic coma state II/III (Harner 1975, Frowein 1982, Pfurtscheller 1985).

Therapies using the protective potency of thiopental (n = 5), midazolam (n = 20), Na + gamma-OH-butyrate (n = 20), procaine (n = 5) (Astrup 1981), and nimodipine (n = 20) were compared. Controlled ventilation (FiO_2, 0.5 intermittent positive pressure breathing; positive end expiratory pressure 5 cm H_2O) should avoid different perfusion patterns. Objective actual cerebral function level and efficiency control were ensured.

Monitoring was performed using conventional electroencephalograms (EEG) (10 channels, bipolaric charge; indication and dosage); microprocessed EEGs (compressed spectral array, Neurotrac, Lifescan, marking the spectral edge frequencies [SEFs; trend analysis]); and somatosensory evoked potentials, central conduction time (CCT), N20-N14 latency, and cortical primary complex (N20/P25-amplitude) (prognosis). Measurements were taken before and after treatment.

In cases of generalized 3 s/spike/waves activity, 175 μV initial injections of thiopentone 100 mg and added infusions of 2 $mg/kg^{-1}/h^{-1}$ reestablished 4-7/8-12/s,25-50 μV rhythm. Latent increased depolarization tendency (high voltage 4-7/s- and sharp waves midazolam 0.14 mg/kg^{-1} per injection, U, 26 $mg/kg^{-1}/h^{-1}$ per infusion) restored voltage stable (25 μV) 8-12/s- activity. Metabolic-induced coma state (posttraumatic lactate accumulation, hepatogenic encephalopathy) characterized by 1-2/4-7/s or triphasic waves gave reason for use of Na + gamma-OH-butyrate 5 $mg/kg^{-1}/h^{-1}$. The known gamma aminobutyric acid (GABA)ergic and dopaminergic qualities were proven by reintegration of 8-12/s rhythm, reduction of blood/cerebrospinal fluid-lactate difference from 2.3 to 1.0 mmol/L, and Glasgow coma score from 5 to 9.4. Irregular 1-2/s waves and partial voltage loss indicated procaine infusion (0.7–1.0 mg/kg/min) (conditions: normovolemia, absence of seizures, direct arterial blood pressure measurement) with resulting desynchronization, 4-7/s activity with superposed 8-12/s frequencies, lactate reduction from 2.8 to 0.4 mmol/1.5. Flattening of the EEG in connection with subarachnoid hemorrhage (n = 10) and open heart surgery (n = 10) (postresuscitation, postperfusion syndrome; Heuser, 1982) required nimodipine (30 $\mu g/kg^{-1}/h^{-1}$), promoting reintegration of 8-5-6/s-activity. Criteria of favorable prognosis—EEG reactivity (Pfurtscheller 1983), alpha activity greater than 50%, spindles, SEF 20 Hz, CCT less than 7.2 msec, N20/P25 amplitude 8.8–1.0 μV—occurred in 40 patients.

CONTINUOUS CENTRAL NERVOUS SYSTEM MONITORING OF HEPATIC COMA

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Hepatic encephalopathy is a psychoneurologic disorder that occurs during severe acute or chronic liver failure. The clinical manifestation can vary from a mild dementia to deep coma. Approximately 30% of patients with cirrhosis die in, if not from, hepatic coma. A major problem in this field is a lack of adequate quantitative measurement of brain malfunction. Measurements of the depth of coma and indicators of seizure activity can help in the management of these patients.

Special variables derived from the electroencephalogram (EEG) have successfully been used to determine the depth of hepatic coma [1]. These calculations were performed off-line, which is not acceptable for monitoring applications. We have developed a prototype brain monitoring system for patients in hepatic coma which can be used for assessing the depth of coma as well as for tracking the occurrences of seizures and other EEG features.

Six patients have been monitored in our preliminary study at Thomas Jefferson University Hospital. The patients were admitted with cirrhosis, hepatitis, or Wilson's disease. The length of time monitored ranged from 1 to 6 weeks continuously. Patients were monitored only while severely obtunded or in coma. Two patients recovered normally, 2 recovered following liver transplantation, and 1 died.

Our prototype monitoring system consists of a four-channel EEG amplifier/processor system (Interspec, Inc) connected to a Macintosh computer for analysis and display. Software was written to trend a variety of variables computed

from the EEG spectrum over variable periods of time. Raw EEG data were also available for viewing and storage.

From our initial experience, we observed the following: (1) from the total power, mean dominant frequency, and percent delta, we could assess the depth of coma, confirming the results of van der Rijt and associates [1]; (2) seizures could be identified and tracked in the total power and percent delta, although some artifacts produced similar patterns; (3) depth of coma induced by barbiturates could also be tracked; and (4) mean dominant frequency seemed to correlate inversely with ammonia levels.

In summary, our preliminary experience indicates a potential for this type of monitoring to be incorporated into the routine care of patients with liver failure. Much work needs to be done to improve the specificity and sensitivity of the methods for tracking depth of the coma and seizures.

REFERENCE

1. van der Rijt CCD, Solko WS, de Groot GH, et al. Objective measurement of hepatic encephalopathy by means of automated EEG analysis. Electroencephalogr Clin Neurophysiol 1984;57:423–426

SEDATION FOR MECHANICAL VENTILATION

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The sedation of mechanically ventilated patients should reduce pain and fear. The intensivist wants to induce changes in the depth of sedation according to the patient's needs. The consequences of different sedative regimens on the electroencephalogram (EEG) and the adaptation of the patient to the ventilatory support should be evaluated.

Forty patients were sedated by intermittent boli of midazolam, 10 patients received midazolam by an infusion with an infusion rate of 0.4 to 0.8 mg/kg/hr, and 10 patients were sedated with an infusion of propofol with an infusion rate of 1.5 to 2.5 mg/kg/hr. Time of respiratory support ranged from 2 to 40 days. Daily EEG recordings according to the 10-20 system were performed. The mode of ventilation, arterial blood gases, and time for recovery were protocoled.

The different stages of anesthesia could be controlled by EEG monitoring. In patients with propofol infusion, flat stages with a low relative power of delta (40 to 50%) are dominating. Midazolam sedation with an infusion or repeated boli are characterized by a high relative power of delta (60–80%) and an increasing amount of beta (10–20%) when the sedative depth is flattening. The EEG monitoring for the control of the dosage of sedatives can be used for midazolam or propofol infusion.

Under sedation with intermittent injections of midazolam, unwanted and sudden changes in the depth of sedation (e.g., a flattening) could be demonstrated. A homogeneous toleration of controlled ventilation could not be achieved. With midazolam infusion, increasing deepening of the sedation could be seen. The weaning period was prolonged. During an infusion with propofol, a smooth steady state of sedation could be achieved.

A sedative therapy administered to the patients' needs, according to EEG changes, can facilitate the respiratory support by minimizing the oxygen consumption and avoiding unwanted stress and can improve the adaptation of the patient to the ventilator. The weaning period can be facilitated.

BENZODIAZEPINE AND THIOPENTAL BOLUS-INDUCED ELECTROENCEPHALOGRAPHIC CHANGES IN COMATOSE PATIENTS TO EVALUATE THE EARLY PROGNOSIS OF SPONTANEOUS OR TRAUMATIC HEMORRHAGES

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In a study of 70 comatose patients suffering from severe intracranial lesions (injuries or spontaneous intracerebral hemorrhage), the fast Fourier transformation of the electroencephalogram (EEG) in compressed spectral array presentation was taken at different times, both before and after administration of central acting substances. Each patient underwent multiple EEG recordings and the EEG reaction was compared with the response pattern after drug administration elicited in healthy individuals. Of 70 patients, 24 showed a general reduction of EEG activity after thiopental bolus injection (0.1–0.4 gm). In 22 of these 24 patients, the decrease of absolute power in all frequencies was irreversible. These patients died of decerebration due to severe intracranial lesions. Both patients with secondary EEG stimulation survived. Also, 44 of 48 patients with permanent EEG stimulation and a significant increase of power in all frequencies survived. Nevertheless, thiopental-induced EEG stimulation differs reliably only between those patients who died due to their cerebral lesion and those who survived, regardless of the functional conditions of survival. A primary excessive activation of all frequency bands seems to be associated more often with the onset of later persistent coma than with a functionally more favorable outcome. Recordings after the administration of midazolam (5–7.5 mg) and the application of its antagonist, flumazenil (0.3–0.5 mg), reveal a more different EEG response. Patients with a poor prognosis not only demonstrated a lack of stimulation, but also a reduction of activity in the frequency bands delta, theta, and beta. Under these unfavorable conditions, flumazenil was able to only compensate partially for these EEG reductions.

Our preliminary results seem to allow the cautious conclusion that EEG spectral analysis after these agents permits a more differentiated prognostic assessment compared with the EEG reactions after thiopental. Furthermore, midazolam-induced changes have an earlier onset than EEG reactions after thiopental administration.

INTRACRANIAL PRESSURE EFFECTS OF VENOUS DRAINING—AN EXPERIMENTAL STUDY IN SWINE

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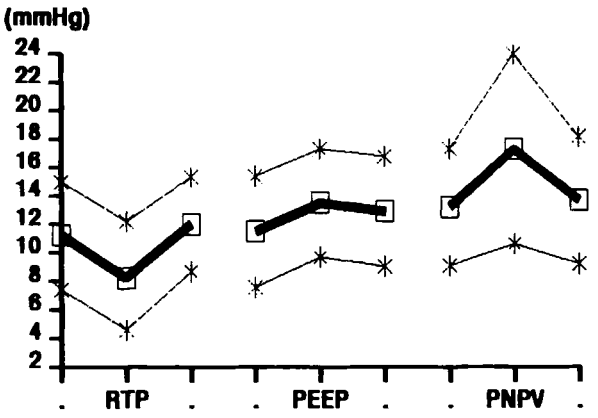
The intracranial cavity is not a closed system, since cerebral blood vessels and the cerebrospinal fluid (CSF) system both communicate with the extracranial circulation. Particular significance is placed on continuous inflow and outflow of blood and CSF, the intracranial pressure (ICP) reflecting this dynamic balance. Perturbation of this balance, especially venous impedance, leads to an increase of the intracranial volume and ICP. We investigated the effects of a reversed Trendelenburg position at 10 degrees (RTP), positive-negative pressure ventilation (PNPV), and ventilation, using positive end-expiratory pressure (PEEP), on ICP.



Intracranial pressure during reverse Trendelenburg position, ventilation using PEEP, and PNPV before, during, and after each maneuver.

The protocol was approved by the institutional animal investigation committee. Ten piglets (body weight, 26 kg; mean, 23–29 kg) were premedicated with azaperone, anesthetized with piritramide, intubated, and instrumented (arterial line, PA catheter, ventricle catheter). Normoventilation was achieved by end-tidal capnometry. RTP was performed on a tipping platform, PEEP was adjusted at +10 mm Hg, and PNPV was implemented with a ventilation pressure +25/−15 mm Hg. Measurements were made 5 minutes after each maneuver, control measurements being taken before and 5 minutes after each period. Derived variables were calculated using standard formulas. Statistical evaluation was done with the *t* test.

Changes Accompanied by Corresponding Alterations of Other Variables (Mean ± SD)

	PNPV	RTP	PEEP
ICP	11.2 ± 3.7	11.5 ± 3.8	13.2 ± 4
	8.4 ± 3.8	13.5 ± 3.8	17.3 ± 6
	12.0 ± 3.3	12.8 ± 3.8	13.6 ± 4
CCP	82.4 ± 20	87.4 ± 15	74.4 ± 13
	79.9 ± 19	69.0 ± 16	66.7 ± 10
	77.7 ± 18	73.8 ± 12	68.4 ± 18
CVP	6.6 ± 2.4	5.5 ± 2.1	5.8 ± 2.3
	5.2 ± 1.6	7.3 ± 2.0	4.6 ± 3.3
	5.3 ± 2.2	5.7 ± 2.0	6.2 ± 3.4
PC	5.8 ± 2.6	5.0 ± 2.1	5.7 ± 1.9
	3.8 ± 2.0	7.7 ± 1.5	2.4 ± 3.1
	5.1 ± 2.2	5.2 ± 2.1	6.1 ± 2.1
ET CO_2	4.3 ± 0.4	4.3 ± 0.4	4.2 ± 0.3
	4.3 ± 0.5	4.2 ± 0.6	4.6 ± 0.5
	4.4 ± 0.4	4.2 ± 0.3	4.4 ± 0.4
SvO_2	60.3 ± 14	59.5 ± 17	57.2 ± 16
	60.0 ± 15	55.4 ± 18	48.3 ± 12
	61.9 ± 15	60.4 ± 17	57.8 ± 15
SaO_2			98.1 ± 1.0
			90.7 ± 7.6
			97.8 ± 1.2

RTP resulted in a decrease of ICP, PEEP led to a small increase, and PNPV caused a considerable increase (Figure). These changes were accompanied by corresponding alterations of other variables (Table).

RTP provides the maximum fall in ICP with the least decrease in mean arterial pressure. While PEEP may be required to improve oxygenation, it must be expected to increase ICP by its effects on intrathoracic and venous pressure [1]. In our study, PNPV led to a marked increase in ICP, in contrast to other investigations [2]. While the ICP effects of RTP and PEEP are explained by concomitant changes of CVP, this is not the case for PNPV. The increase in ICP, coinciding with a decrease in CVP during PNPV, appears to be due to some degree of hypercapnia in combination with pronounced hypoxemia. The latter is reflected by a decreased SvO_2 and SaO_2 and is caused by atelectasis, produced by the negative pressure phase. We conclude that, with respect to ICP increase, PEEP may not be as harmful as previously thought and that RTP is an old but very useful way of reducing ICP. With respect to ICP, pulmonary function, and hemodynamics, PNPV produces a number of undesirable effects and should not be part of any anesthetic protocol.

REFERENCES

1. Hoffmann P, et al. Intrakranieller Druck und Kreislaufparameter bei erhöhtem endexspiratorischen Druck. Anaesthesist 1986;35:721
2. Cunitz G, et al. Beeinflussung des intracraniellen Druckes bei neurochirurgischen Operationen durch Hyperventilation, PNPV und PEEP. Anaesthesist 1979;28:142

MODEL FOR IDENTIFICATION OF THE CEREBRAL BLOOD FLOW CONTROL SYSTEM

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A generalized model of the regulation of local circulation was developed on the basis of the assumption that the goal of the control was to maintain the energy content of the living tissue. As a further step, these elementary circulatory units had coupled to each other and a complex regulatory system model of cerebral blood flow was constructed.

The model was realized on a personal AT-compatible laptop computer. The input signal of the model was the arterial blood pressure recorded from the carotid artery of a cat. The output signals were the simulated arterial blood flows, the precapillary pressures, the mean potential energy density, the temperature of brain tissues, the intracranial pressure, concentrations of O_2 and CO_2, and the different kinds of ions in the brain tissues.

The appropriateness of energetic considerations of the hypothesis and the proper construction of the model were confirmed by the similarity of the simulated flow patterns. The performance of the model suggests that the well-known regulatory phenomena of the local circulation are the results of a set point-free control system.

Computer realization of the model has validated both the hypothesis and the construction of the model and has provided a wide range of applications in predicting local circulatory variables in the central nervous system under various conditions.

ANESTHETIC DRUGS AND TRANSCRANIAL BLOOD FLOW VELOCITIES

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Intravenous anesthetics, with the exception of ketamine, depress cerebral blood flow (CBF). Inhalational anesthetics have the opposite effect, whereas narcotics and neuroleptics used in neuroleptanalgesia leave CBF nearly unchanged as long as ventilation is adequately maintained [1]. During cardiopulmonary bypass and cross-clamping of the carotid artery, transcranial Doppler sonography has been used for monitoring cerebral circulation. Systematic investigation of the effects of anesthetic agents on mean blood flow velocities (v) in cerebral arteries have been nearly neglected. We studied three groups of 10 adult patients, each undergoing minor surgical or gynecologic operations, using TC 2-64 (EME) equipment [2].

In group I, thiopental (5 mg/kg body weight) was injected over a period of 30 seconds. In group II, halothane (1 vol%) was administered, and in group III, a neuroleptanalgesic agent was administered. Ventilation was maintained in groups II and III by a ventilator using a mixture of N20:02 = 2:1 and controlled by capnometry. Capillary P_{CO_2} ranged from 35 to 40 mm Hg. In group I, mean blood flow velocity in middle cerebral artery (vMCA) was measured in the awake state and 60 seconds after injection of the barbiturate. In groups II and III, vMCA, blood pressure, and heart rate were determined before anesthesia (A), during anesthesia (B), and after skin incision (C).

Thiopental reduced vMCA by more than 33%, from 45.8 ± 4.5 to 30.4 ± 9.8 cm/s ($P < 0.001$). Halothane caused a significant increase in vMCA, from 54 ± 12.8 (time A) to 84.2 ± 23.9 (time B) and, finally, to 98.2 ± 26.4 (time C). Neuroleptanalgesia left vMCA unaltered. Blood pressure dropped in group I but did not change significantly in groups II and III.

Our results show that some anesthetic agents influence blood flow velocities to an extent similar to that reported for CBF. The anesthetic agent as well as ventilation, especially arterial P_{CO_2}, should therefore be taken into consideration while monitoring vMCA during surgery and intensive care.

REFERENCES

1. Smith AL, Wollmann H. Cerebral blood flow and metabolism: effect of anesthetic drugs und techniques. Anesthesiology 1972;36:378
2. Aaslid R, Markwalder TM, Nornes H. Noninvasive transcranial Doppler ultrasound recording of flow velocity in basal cerebral arteries. J Neurosurg 1982;57:769

TRANSCRANIAL DOPPLER SONOGRAPHY DURING ANESTHESIA AND INTENSIVE CARE

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Cerebral blood flow (CBF) can be compromised severely during anesthesia and intensive care. Transcranial Doppler sonography (TCD) offers the chance of a noninvasive and sensitive monitoring of blood flow velocities in basal cerebral arteries [1]. Assuming constant diameters of the investigated vessels, altered flow velocities reflect real CBF alterations.

Clinical applications of the method will be presented: CO_2 reactivity and autoregulation can be tested preoperatively and intraoperatively. This is relevant in patients with brain tumors, brain injuries, and subarachnoid hemorrhage (SAH) or during carotid endarterectomy or cardiopulmonary bypass. Cerebral blood flow as well as flow velocities are influenced by anesthetic agents like halothane and thiopental. Furthermore, the effects of postural variation on the intracranial circulation were demonstrated with this technique during intensive care and anesthesia. The importance of TCD for diagnosis and therapy control of cerebral vasospasm after SAH is well accepted. Increased intracranial pressure leads to specific curve forms. Continuous recording can show the effects of drugs or therapeutic interventions. When clinical signs of brain death occur, TCD is of value for timing definite diagnostic procedures.

Pitfalls of the method have to be discussed as well. As long as the diameters of the investigated vessels remain unknown, clinical decisions derived from TCD measurements should be made carefully [2]. Recent animal experiments on resistance of large cerebral arteries do not support the assumption of constant vessel diameters under the influence of certain anesthetic agents and blood pressure alterations.

REFERENCES

1. Aaslid R, Markwalder TM, Nores H. Noninvasive transcranial Doppler ultrasound recording of flow velocity in basal cerebral arteries. J Neurosurg 1982;57:769
2. Schregel W, Cunitz G. Derzeitige Möglichkeiten und Grenzen der transkraniellen Dopplersonographie als zerebrales Monitoringverfahren. Anasth Intensivther Notfallmed 1989;24:11

FUNCTIONAL ELECTROENCEPHALOGRAPHIC FREQUENCY ANALYSIS AND TRANSCRANIAL DOPPLER SONOGRAPHY AS METHODS TO ASSESS THE EFFECTIVENESS OF OSMOTIC THERAPY

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To evaluate the therapeutic benefit of osmotic agents in comatose patients with severe intracerebral lesions accompanied by brain edema and increased intracranial pressure, we commonly use indirect variables such as intracranial pressure monitoring. In contrast, electroencephalographic (EEG) frequency analysis may observe the direct influence on neuronal structures after osmotherapeutic interventions. We repeatedly performed an EEG spectral analysis lasting 2 hours during the administration of 150 to 250 ml sorbitol 40% in 20 patients with such severe intracranial lesions as head injuries, spontaneous intracerebral hemorrhage, or subarachnoid hemorrhage. Initially, the positive influence of the therapeutic regimen on the EEG is a stimulation in the alpha and beta range and a synchronous reduction of the delta range. This favorable alteration decreased after the first 3 days, particularly over the more severely affected hemisphere. In addition, in 12 patients, the cerebrospinal fluid to serum ratio of albumin, as described by Reiber [1], was calculated to evaluate the extent of simultaneous blood-brain barrier disturbances. Eighty percent of patients with pathologic elevation of this ratio did not demon-

strate any signs of EEG activation after osmotic therapy and even partially developed a rebound phenomenon.

To assess the influence of osmotic therapy on blood velocity as measured by a transcranial Doppler catheter, in 6 additional patients, a fast Fourier analysis of Doppler spectra was performed before and after therapy. Similar to previous studies, heart rate increased by 14%. High frequencies increased in intensity, suggesting a higher percentage of fast-moving blood cells. In addition, turbulence increased, as indicated by negative frequencies. The highest increase in blood flow velocity was during peak systole, increasing by as much as 90%. Mean blood flow velocity, as integrated over a heart cycle, increased by 20% in 2 patients, and by more than 50% in 4. Pulsatility indices dropped in the latter 4 patients from over 2 to less than 1. This suggests a decrease in peripheral vascular resistance in the brain vessels as described by Gosling and colleagues [2].

Our results indicate that there is no general benefit from prolonged osmotic therapy. In some patients, however, especially those with a well-functioning blood-brain barrier, short-term increases in basal artery blood flow can be achieved. No such effect can be seen in patients with massive barrier disturbances.

REFERENCES

1. Reiber H. Eine aktuelle Darstellung des Liquorproteinprofils zur Differentialdiagnostik von Schrankenfunktionsstörungen und entzündlichen Prozessen des ZNS. Acta Neurol 1980;7:127
2. Gosling R, et al. The significance of the Doppler pulsatility index in the basal cerebral arteries. 2nd International Congress on Transcranial Doppler Sonography, Salzburg, 1988

TRANSCRANIAL DOPPLER ULTRASONOGRAPHY IN THE DIAGNOSIS OF BRAIN DEATH

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From November 1987 to July 1989, 7 patients with recent clinical and electroencephalographic signs of brain death were studied via a transcranial Doppler device; the cause of death was cerebrovascular accident in 4 cases and trauma in the remaining 3. The middle cerebral (MCA) and ophthalmic (OphA) arteries were examined from each side. The data we obtained are given in the Table.

The direction of OphA flow in all the patients with ICP greater than MAP was reversed. This phenomenon was demonstrated in one patient by the use of four-vessel angiography, which also showed a cessation of cerebral circulation. Furthermore, the direction of flow in the patients with increased ICP but decreased MAP was physiologic. These two phenomena suggest the possibility that the transcranial Doppler device could demonstrate the disappearance of cerebral perfusion pressure in patients with clinical and other instrumental data consistent with the diagnosis of brain death. However, the scantiness of our case records and the lack of ICP monitoring in 2 cases with physiologic OphA directional flow do not allow a definitive conclusion. Further studies are needed.

In contrast, the demonstration of a relationship between ICP values and ultrasonography data, and the finding of characteristic wave profiles in brain dead patients, as proved by other investigators [1,2] confirm the usefulness of transcranial Doppler ultrasonography in the evaluation of the lack of efficacious cerebral flow in patients who will be examined for the diagnosis of brain death.

REFERENCES

1. Ropper AH, Kehne SM, Wechsler L. Transcranial Doppler in brain death. Neurology 1987;37:1733
2. Hassler W, Steinmetz H, Gawlowski J. Transcranial doppler ultrasonography in raised intracranial pressure and in intracranial circulatory arrest. J Neurosurg 1988;68:745

CLINICAL AND INSTRUMENTAL CENTRAL NERVOUS SYSTEM MONITORING IN THE DIAGNOSIS OF BRAIN DEATH: AN ITALIAN EXPERIENCE

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From December 1982 to December 1988 in our intensive care unit, 70 severely brain-injured patients were declared brain dead and then became organ donors (mean age, 31 yr; range, 5–56 yr). Primary cause of death was trauma in 38 patients (mean age, 26 yr) and cerebrovascular accident in the remaining 32 patients (mean age, 37 yr). As required by Italian law, diagnosis of brain death was made in all cases by clinical examination and demonstration of electrocerebral silence on an eight-channel electroencephalographic device. Clinical examination consisted of verification of the absence of the brainstem reflexes, of plantar reflexes, and of spontaneous breathing after disconnection of the ventilator for 2 minutes or until a $PaCO_2$ threshold (>60 mm Hg) was reached. Problems came from the required absence of plantar reflexes: sometimes slight movements of the toes persisted for a long time after the pa-

Data Obtained

	Patient No.						
	1	2	3	4	5	6	7
MCA	NF	NF	NF	LSP	LSP	LSP	OF
OphA	IF	IF	PF	PF	PF	PF	IF
ICP	>MAP	>MAP	<MAP	<MAP	NR	NR	>MAP

Abbreviations: NF, no flow; IF, inverted direction of flow; PF, physiologic direction of flow; OF, oscillating flow; LSP, little systolic peak followed by diastolic levelling; NR, not recorded; ICP, intracranial pressure; MAP, mean arterial pressure.

tient met all the other clinical and instrumental criteria of brain death. In a few cases, this may have been caused by an irreversible decay of cardiovascular function, which in turn decreased the usefulness of the patients as donors.

In 26 cases, brainstem acoustic-evoked potentials (BAEPs) were recorded during contralateral masking and single-ear stimulation was repeated on each side. The BAEPs always demonstrated the absence or the progressive disappearance of the waves following the first one and, later, of the first wave itself.

Ten cases were studied using somatosensory evoked potentials recorded at the Erb's, cervical, and cortical levels during median nerve stimulation and repeated on each side; each patient showed the absence or the progressive disappearance of cortical waves and the persistence of the cervical waves (latency, <14 msec).

Intracranial pressure (ICP) and, indirectly, cerebral perfusion monitoring, carried out in 28 cases, gave important information for a more effective and timely evaluation of the patients and for a better and more rational administration of central nervous system (CNS) depressant drugs. In this way, barbiturates were used only in selected patients and could be stopped when no more were required (in cases of normal ICP or those that could not be controlled by therapy), resulting in fewer problems for CNS monitoring.

In 3 patients, cerebral blood flow was also evaluated with a transcranial Doppler device, which always demonstrated velocimetric profiles consistent with the absence of an effective cerebral circulation.

The excellent agreement of all the clinical and instrumental data confirm the feasibility of a certain and completely reliable diagnosis of brain death, as also declared by the Nord Italia Transplant Scientific Committee, which met October 7–8, 1988.