Continuous EEG-SEP monitoring of severely brain injured patients in NICU: methods and feasibility

Utilisation de l’EEG et des potentiels évoqués somesthésiques en vue d’un monitorage continu de la souffrance cérébrale en unité de soins intensifs : méthodes et faisabilité

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Abstract

\textbf{Aims.} - To evaluate the feasibility of a continuous neurophysiologic monitoring (electroencephalography (EEG)-somatosensory evoked potentials (SEPs)) in the neuro-intensive care unit (NICU), taking into account both the technical and medical aspects that are specific of this environment.

\textbf{Methods.} - We used an extension of the recording software that is routinely used in our unit of clinical neurophysiology. It performs cycles of alternate EEG and SEP recordings. Raw traces and trends are simultaneously displayed. Patient head and stimulator box are placed behind the bed and linked to the ICU monitoring terminal through optic fibers. The NICU staff has been trained to note directly clinical events, main artefacts and therapeutic changes. The hospital local area network (LAN) enables remote monitoring survey.

\textbf{Results.} - Continuous EEG (CEEG)-SEP monitoring was performed in 44 patients. Problems of needle detachment were seldomly encountered, thanks to the use of a sterile plastic dressing, which covers needles. We never had infection or skin lesions due to needles or the electrical stimulator. The frequent administration of sedative at high doses prevented us from having a clinically valuable EEG in several cases but SEPs were always monitorable, independently of the level of EEG suppression. The diagnosis of seizures and non-epileptic status was based on...
Introduction

Many articles and reviews [11,14,19,34] underlined the importance of monitoring brain function in neuro-intensive care unit (NICU). Neurophysiologic techniques have peculiar advantages for this purpose: they are sensitive to hypoxia-ischemia and metabolic alterations and are irreplaceable for diagnosis and treatment of seizures and status epilepticus [35]. Moreover, neurophysiologic tests have a prognostic value for the major types of coma [2,3,21,25,26,33], are useful to evaluate the effects of sedative drugs [24], and, finally, have a low cost and can be performed at the patient’s bedside. Moreover, monitoring software can be the extension of a routinely used digital electroencephalography (EEG) system. Overall, keeping in mind that comatose patients can be hardly assessable clinically because of the severity of coma or of sedation, neurophysiologic monitoring provides the intensivist with the most straightforward method for an objective evaluation of the functional neurological status.

Nevertheless, while there is a widespread use of pressure (intracranial cerebral pressure, ICP), hemodynamic (Transcranial Doppler, TCD) and metabolic (Jugular saturation of O₂, SJO₂) monitoring, there are fewer data [4,8,10,15] on the usefulness and clinical impact of neurophysiologic monitoring. Raw EEG and quantitative EEG (QEEG) are currently used for the diagnosis and treatment of epilepticus status, not only in epileptic patients, but also in acute brain injury (ABI) [5,16,22,23,32]. Instead, there are less data on the neurophysiologic (EEG) contribution to survey the evolution of primary brain damage and the occurrence of secondary damage in ABI. Several quantitative parameters have been searched for and proposed, mainly for ischemic complications, but, currently, their clinical usefulness is still matter of debate [5,16,28,29]. In this context it is surprising that evoked potentials, which are widely used in intraoperative monitoring (IOM), still have a very scarce use in the NICU. Till now, there has been only one Canadian group [13,19], that performed continuous somatosensory evoked potential (SEP) monitoring to survey the evolution...
of traumatic ABI. Hence, theoretically, a patient who was monitored in the operating room could benefit from a prolongation of monitoring during his postoperative NICU stay, till early stabilization of his neurological function.

We believe that it is particularly useful to combine the advantages of both the high EEG sensitivity to hypoxic-ischemic, metabolic and epileptic events, and of the relative insensitivity (and, thus, stability) of early SEP components to neurosedation. Moreover, it is particularly easy to introduce SEP parameters in trend curves. Therefore, continuous SEP monitoring could counterbalance the high physiological EEG variability and extreme sensibility to neurosedation.

This paper aims at assessing the feasibility of a continuous neurophysiologic monitoring (continuous EEG (CEEG)-SEP) in the NICU, taking into account both the technical and medical aspects that are specific of that environment, particularly, settings, materials, software and interaction between NICU and neurophysiologic staff. Proving the efficacy of CEEG-SEP in detecting the deterioration of neurological function in brain-injured patients is beyond the scope of this study and will be discussed in a future paper.

Methods

System layout

The EEG-SEP recording system consists of a PC, which is located on a cart-carryage at the bottom of NICU, far from the patient bedside. This is connected by a serial interface to an amplification head-box 2 AC/DC (BE-light, EB Neuro, Italy) and a multimodal stimulator (MMS, EB Neuro, Italy). The head-box and the stimulator are both fastened by means of a flexible metallic arm, 1.5 m behind the patient’s head, thus not interfering with NICU staff management of the patients from behind. We use a small head-box (135 × 100 × 35 mm) with 28 channels: 21 monopolar, four bipolar. The acquired data are transmitted to the PC by means of an optical fiber.

Recording system

Electrodes

We use straight stainless steel needle electrodes, which are certified to be safe for 48 hours. These are gathered in plaits of colored strings and the NICU staff has been instructed to replace electrodes on the basis of a colored scheme located at bedside (Fig. 1). The positions of the electrodes on the patient-head are marked with a dermographic pen. Such marks, furthermore, guarantee the precise replacement of the needles when the technical personnel has to substitute them every 48-72 hours.

Electrophysiological tests

EEG. Digital EEG is acquired through eight electrodes at the locations F3, C3, T3, P3, F4, C4, T4, P4 of the International 10-20 System. These are referred to a reference electrode at midpoint between Fz and Cz. Occipital electrodes are excluded because of a higher probability of artefacts. Six bipolar channels are visualized for raw EEG: F3-C3, C3-T3, T3-P3, F4-C4, C4-T4, T4-P4.

SEPs. SEPs are obtained to electrical stimulation of the right and left median nerve at the wrist. We use a homemade stimulator that consists of a 4-cm large strip-stretch material, containing two convex, digitally controlled disc electrodes (3 cm apart). Stimulus intensity is 4-5 mA above motor threshold; pulse duration is 0.2 ms; stimulus rate 3 Hz. Importantly, the arterial cannula may not be located in the radial artery because the strip would prevent drug infusion and, conversely, nurses’ actions on the cannula would risk dislocating the stimulator.

For SEP recording, two elastic ground strip are placed on patient’s arms. Electrodes are placed at Erb’s point (referred to contralateral Erb’s point), spinous process Cv7 (referred to anterior neck), C3 and C4 (referred both to Fz and ipsilateral mastoid). Time base is 100 ms; bandwidth 5 Hz-3 KHz; sampling frequency: 4000 Hz at least two averages of 250 responses are repeated and superimposed. N9, N13, P14, and N20 latencies are measured. We determine peak-to-peak amplitude of N20/P25 using Fz reference; P25 is identified as the major positive peak following N20.

When cortical SEPs are bilaterally present, continuous neuromonitoring is obtained from both hemispheres by alternately stimulating the right and left median nerve with a right/left interstimulus interval of 333 ms. During monitoring we usually visualize C3’/C4’-Fz and Erb1-Erb2 responses.

Monitoring system

The software that we use for continuous EEG-SEP monitoring is an extension of the recording software that we routinely use in our Clinical Neuropysiology Unit (CNU), with which the medical and technical staff are already confident. This software allows the setting of cycles of alternate EEG/SEP recording. We can choose the length of each EEG
and SEP session and state the number of cycles to be performed for a long-term monitoring.

At any time we can pause monitoring (for example, during patient nursing). Furthermore, annotations (such as artefacts, therapeutic changes, and reactivity modification) can be on-line added. Raw data (such as EEG and EP traces) are stored and always available, and the system provides automatic analysis tools to extract quantitative parameters of QEEG and SEP.

EEG
An EEG session usually spans 60 min but can be interrupted at any moment to start a SEP session without interrupting the cycle. During an EEG session we can recall the entire recording till 20 s before online visualization; we can also visualize the recorded SEPs.

EEG traces are displayed on one side of the screen, and QEEG on the other side. QEEG consists of both frequency (compressed spectral array, CSA and bar representation) and amplitude (percentage of burst-suppression) analysis. Spectral powers are calculated for each channel covering the frontal, parietal, and temporal regions. QEEG provides CSA or, for further time compression, a bar representation of both a single frequency band, expressed as the percentage of the total power, and of a band ratio (for example alpha/delta, etc).

QEEG analysis also provides an algorithm, which is based on EEG amplitude analysis and calculates the percentage of EEG suppression during neuroprotection. This algorithm can be applied to those channels that are considered the most relevant. Analyses are performed on single 1-s epochs; each epoch is considered suppressed if 100% of it has an amplitude lower than 5 μV. Every 30 s the software provides suppression percentage with a bar representation (i.e. the higher the bar, the greater the suppression).

SEPs
Both the used montage and the length of the SEP session are set through a user-defined macro. The length of each SEP session (usually 6-12 min) is enough to record at least three complete traces (250 averages) for each channel.

Once the macro has been chosen, we record a first trace, which is labeled on as the template, to which the following traces are compared. We manually locate the markers of the principal waves (N20 latency and N20-P25 amplitude), then we start the session. The software automatically recognize N20 and P25 peaks and puts the marker on the maximum negative and positive deflection within a window of ± 2.5 ms with respect to the position of the markers on the previous trace (taken as “relative zero”). Labeled peaks can be reviewed and manually corrected if necessary.

Traces are displayed in cascades (8-32) on one side of the screen, while the trends of SEP latencies and amplitude are displayed on the other side (Fig. 2). Lines of different colors for amplitude and latency values represent this trend. A horizontal baseline represents latency and amplitude of the template; latency and/or amplitude modifications cause the lines diverge from the baseline.

The software provides visual alerts. We can set the limits of latency increase and amplitude decrease that are considered significant. During monitoring, we can change the template and calculate a new trend with reference to this new template. This avoids restarting a new cycle. This

![Figure 2](image-url) Example of bilateral SEPs to left/right median nerve stimulation in a 40-year-old man who suffered from traumatic brain injury with large right lenticulo-capsular hemorrhage. This caused a significant decrease in the amplitude of the N20-P25 complex to left median nerve stimulation (i.e. right hemisphere). (Left): Raw SEP waveforms with automatically detected peaks N20-P25. The red traces correspond to the averaged templates; the “●” symbol denotes the peak of interest. Time progression goes from bottom to top. Bottom single traces are derived from both Erb’s-points. Each trace is labeled with its recording time. (Right): Latency and amplitude trends for both hemispheres. Blue and grey lines represent the latency and amplitude alarms, respectively.
possibility is useful in case of SEP changes due, for example, to neurosedation.

At the end of SEP session, the software automatically starts the EEG session independently of the number of recorded traces, thereby preventing the possibility of a repetitive endless patient’s stimulation when the required number of artefact-free sweeps is never reached, as in case of electrode detachment. Only completed averages are saved at the end of the SEP session.

Data collection

An electronic sheet is filled with the monitored parameters such as cerebral perfusion pressure (CPP), ICP, MAP, temperature, PCO₂, SO₂, etc. Any therapeutic change is also notified (e.g. allowing correlation between drugs and SEPs amplitude changes) (Fig. 3). On the same sheet, GCS, photomotor response and any clinical or neuroradiological change are noted.

Local and remote review

The recording PC allows NICU staff a local overview of the monitoring. Furthermore, thanks to the local area network (LAN), the neurophysiologist can review trends along with raw waveforms from its desktop in the different stations of the CNU, thereby facilitating the survey of the monitoring.

Acquired data are temporarily saved on the recording PC. At the end of the monitoring, these are stored on a magnetic device (DVD). A CEEG-SEP monitoring data for 8-10 days occupies about 2.5-3 GB of memory [27]. Sampled data are stored in binary form, and the acquisition parameters can be stored in readable ASCII form.

Monitoring

The neuro-intensivist calls us as soon as an eligible patient (GCS < 9, undergoing ICP monitoring) is admitted in NICU and our technicians performs a baseline neurophysiologic examination, which consists in a standard EEG recording and a four-channel SEP recording on both hemispheres. The results are then discussed with the neuro-intensivist and, unless cortical responses are absent on both hemispheres, we start monitoring. The respective lengths of EEG and SEP sessions are decided on the basis of both the clinical features and the expected evolution of the brain damage.

The technicians provide the montage of the patient using colored plaits and leave on the patients scalp dermographic signs in order to help the NICU staff who is in charge to stick back detached electrodes, if any (for example during nursing). Furthermore, NICU staff is also able to pause monitoring in order to prevent the recording of artefacts when performing nursing. A pause is also made during such patient manipulations as X-ray or TCD examinations, and so on. We survey the monitoring from the remote stations of our unit and discuss with the neuro-intensivist any significant neurophysiologic modifications. For his part, the NICU staff calls us in case of significant variations of the monitored parameters such as ICP and CPP. Furthermore, once a day, we meet the neuro-intensivist and discuss together the course of the monitoring. Whenever the patient needs transportation out of NICU (CT-scan of other), our technicians are in charge of resetting the montage when the patient has been brought back in NICU. Furthermore they are also in charge of changing the electrodes every 48-72 hours.

Monitoring goes on until the monitored parameters are stable and the patient is no more considered at risk of developing brain complications.

Results

From February 2003 to December 2005 we performed a continuous neurophysiologic monitoring in 44 NICU patients. The aetiologies were mainly head trauma and intracranial hemorrhages. CEEG-SEP monitoring was performed in 42 cases while only CEEG was performed in two cases. Mean GCS on admission was 6. Among the 42 patients who underwent CEEG-SEP monitoring, 29 underwent bilateral SEP monitoring and 13 underwent unilateral SEP monitoring because cortical SEP was absent on one hemisphere. Monitoring time was on the average 8 days (range 3-19 days).

Because of the severity of coma and the high level of sedation these patients did not have spontaneous movements, so that we seldom had problems with detachment of needles. Whenever it occurred, thanks to its adequate training, the NICU staff was generally able to stick them back. We sometimes lost some hours of recording because the detachment of the needle had not been noted; this happened especially during the night and the incidence of such events has decreased with the increasing confidence of the NICU staff in the monitoring system. Furthermore, in order to minimize the risk of needle detachment,
we used in the last eight patients a sterile plastic transparent dressing (Tegaderm™), usually used to cover scalp lesions. Practically, we first covered the scalp with the plastic dressing, then located the needles, and, finally, covered these with another layer of dressing. The quality of the signal was the same and, since then, we have never observed needle detachment. It has also become possible to carry the patient to perform a CT scan without removing the needles.

We have never had infection or skin lesions due to the needles or the electrical stimulator. We initially used a metal ground but after we observed an allergic reaction consisting in the appearance of skin stains, we have opted for a strip ground and never got any problems with it. In some patients (five cases) we observed a slight ICP increase during electrical stimulation; in these patients we shortened the length of SEP recording and increased the time interval between SEP sessions.

All patients were sedated with midazolam and/or propofol and/or remifentanil, and 16 underwent iopental infusion. The frequent administration of high doses of sedative prevented us from obtaining a clinically valuable EEG, due to its pharmacological suppression in 23/38 cases. In all these cases SEPs were always monitorable, independently of the level of suppression. Although we observed several types of cortical SEP alterations, due to sedatives, N20 was always monitorable. The most dramatic SEP modifications (latency, amplitude, and morphology) were due to the infusion of high doses of thiopental for long periods (5-6 days), while the effects of bolus were milder and, most often, transitory (Fig. 4).

A non-convulsive status epilepticus (NCSE) was detected in four patients; two of them were monitored only with CEEG as they did not undergo any ICP monitoring. In these cases, the diagnosis of NCSE was based on raw EEG, while QEEG was used to quantify ictal activity as a guide to treatment efficacy. For that purpose, the spectral power of ictal and interictal EEG was first analyzed by means of CSA. On the basis of this preliminary analysis we decided which frequency bands were to be used for bar representation of a single frequency or a frequency ratio (in which the numerator is the ictal frequency and the denominator the interictal frequency, so that, in case of ictal activity there is an increase in the ratio with a consecutive increase in the height of the bars). In three patients we used a “broad alpha” (6-14 Hz)/delta ratio, and, in the other one, we used the single band that characterized the ictal activity (2-4 Hz) (Figs. 5 and 6). Raw EEG was also continuously monitored (Fig. 5).

Among the other 40 patients, we observed nine cases of neurological and/or neurophysiological deterioration, an example of which is shown in Fig. 7. Clinical details about these deteriorations will be discussed in a future paper.

Discussion

In our experience EP and EEG waveforms that we obtained in NICU were of comparable quality to routine clinical measurements and contained the same clinical information. Therefore CEEG-SEP monitoring allowed us to successfully detect both normal and abnormal electrophysiological signals. As a prerequisite for monitoring feasibility we consider that some requirements must be fulfilled on setting, electrodes and montages, staff interaction, consulting and software.

Setting, electrodes, and montage

Most importantly for monitoring feasibility, the EEG-EP system should be an extension of the recording system that is routinely used in the lab, and with which the medical and technical staff has already gained full confidence. Furthermore, in order to be well accepted by the NICU nursing staff, the monitoring equipment should never be a hindrance. For instance, the distance of both head-box and stimulator (1-1.5 m behind the patient’s head) and the location of the main PC (far away from the bed) helped avoid any interference with the NICU staff activities.

Concerning the type of electrodes to use, we followed Jordan’s suggestion [15] and chose straight, subdermal, stainless steel needle electrodes instead of surface electrodes fixed with collodion. Needle electrodes offer several advantages. They can be easily removed and replaced by the NICU staff. They have revealed to be safe for both infections and decubitus lesions. Straight needles, as opposed to bent ones, have a lower risk of skin lesions due to possible stretching of the string. The risk of electrode’s displacement was low given the limited active movement of patients. Furthermore, Tegaderm™ has reduced needle detachment and movement artefacts. The subdermal wire electrodes that were proposed by Ives [12] are, in our opinion, more invasive and cannot be easily stucked back by the NICU staff.

There is not a single optimal EEG montage for NICU. In some instances, head wounds, recent surgical scars, skull defects, and intracerebral catheters may limit electrode placement [14]. An acceptable compromise was using a reduced number of electrodes [17,31]. We chose to use only eight electrodes with bipolar montages excluding occipital electrodes, not only given the increased probability of artefact but also because of the frequent declivous subgaleal edema, and, finally, given the risk of decubitus ulcer. For continuous bedside recording, we used a bipolar montage as suggested by Young et al. [33].

Four channels were used for the baseline SEPs, and two channels for SEP monitoring. To reduce the number of electrodes without loosing essential information, we chose to monitor both the Erb’s potential (in order to verify the efficacy of the peripheral stimulation) and the cortical response. For the latter, we preferred to use a Fz reference because it allows obtain cortical SEPs of greater amplitude and picks up less artefacts, when compared to a mastoid or earlobe reference. Moreover, in our experience the Fz reference makes SEPs more readily monitorable when the cortical response is of low amplitude. We agree with MacDonald et al. [18], who suggested optimizing IOM monitoring by choosing the reference which allows obtaining the greatest cortical SEP amplitude and the highest signal-to-noise ratio. In case of absence and/or loss of the cortical SEP we then used a mastoid reference in order to monitor the P14 component [9].
Consulting and interactions between neurophysiologic and NICU staff

The possibility of using LAN has been fundamental for the performing of monitoring because it has allowed us survey monitoring directly from the CNU. If any monitoring change is noticed on the local display by the NICU staff, the latter will alert a trained clinician who can verify the automatic interpretation by considering the raw waveforms and accordingly recommend appropriate actions. Thanks to LAN, the clinician can check patient’s progress from any securely networked computer.

The personnel integration must be considered at two different levels: between technicians and nurses and between neurophysiologists and neurointensivists. The former level is required for optimizing the technical quality of monitoring, the latter one for the clinical interpretation of neurophysiologic data.

Figure 4  SEPs are still monitorable during thiopental (TPS) infusion in a patient with asymmetric cortical responses. (A) Effect of a bolus of TPS with a consecutive increase in SEP latency and slight waveform modification. Arrows indicate the time when the bolus was administrated. (B) SEPs after TPS infusion for 5 days with a major N20 waveform alteration on the better hemisphere. SEPs were still monitorable, although there was a total suppression of the EEG activity. (C) Progressive recovery of amplitude and latency of the cortical responses and (D), complete recovery back to the pre-infusion SEPs 3 days after TPS withdrawal. The bar graphs in the lower parts of A, B, C, and D represent the percentage evolution of EEG suppression: the higher the bar the higher the percentage of suppression.
On the one hand, an adequate training of NICU staff (replacement of electrodes, online annotations, pausing of the system), its necessary to carry out a prolonged monitoring of several days without a continuous intervention of the technicians. On the other hand, it is essential that the neurophysiologist and the neuro-intensivist cooperate and adopt a common language. The daily discussion turned out to be very useful for the neuro-intensivist in order to integrate neurophysiologic data with the other monitored parameters and with the clinical course of the patient. Furthermore, the neurophysiologist cannot fully interpret CEEG and CEP data without integrating these with the other patient data, particularly his clinical features. Indeed, some factors (levels of centrally active drugs, metabolic disturbances) can have profound effects, mainly on the EEG, while others (hypoxemia, ischemia, significant changes of cerebral perfusion) must be correlated with the monitored variations, if any, of neurophysiologic parameters.

Software: quantitative analysis and trending

The CEEG indications in NICU were discussed mainly for monitoring patients with subarachnoid hemorrhage. Claassen et al. [4], indicated the type of clinical evidence: good for detecting seizures, pilot studies for detecting ischemia from vasospasm, poor evidence for monitoring clinical state, unknown for predicting outcome. In our opinion, CEEG indications can be extended to acute brain damage from different aetiologies (i.e. severe traumatic injury).

Although it is not possible to give up raw EEG, CEEG monitoring requires quantification and trend visualization. Thus, for status epilepticus, which is a major clinical indication of CEEG, the diagnosis is based on raw EEG, while QEEG can be a useful tool to quantify seizures frequency and evaluate the response to therapy [16,30]. Similarly, different QEEG parameters were proposed for detecting delayed ischemia in subarachnoid hemorrhage: total power [17], alpha-ratio [29], alpha/delta ratio [6]; how-
ever, they are still unvalidated and not available online. Even more controversial is the use of CEEG to monitor clinical status in traumatic brain injury. Some authors support its usefulness for the clinical/therapeutic decisions (for example whether to move a patient for a CT scan or not [16]) while others found a poor correlation between QEEG modifications and outcome and, therefore, preferred using SEPs [19].

Given the difficulties to get a consensus on the best QEEG parameters that should be used for monitoring, the high variability of EEG, and its sensitivity to drugs, we decided to associate both EEG and SEP monitoring. The rationale of this choice has several reasons: firstly, SEPs are resistant to medications and are still recordable when the EEG is suppressed. Secondly, thanks to their simple waveform, automatic peak is an easy task, so the trend representation of their latencies and amplitudes allows also non-expert personnel to identify significant SEP changes on-line. An often-mentioned SEP restriction is that they would provide a less widespread cortical assessment than EEG; however, as suggested by Claassen et al. [4] for vasospasm and ischemia, we think that ABI is associated with alterations that are unlikely to entail EEG changes limited to some electrodes consequently these changes can be detected by SEPs provided that they are monitorable on both hemispheres. It’s surprising that so few authors used SEP monitoring in ABI: only the Canadian group of Toronto [13] reported a wide experience that is limited to patients with severe head trauma.

### Integrated EEG-SEP monitoring

Our approach is based on the choice of an integrated EEG-SEP continuous monitoring, the respective parts of each test are individually evaluated, according to which one is likely to be more informative in this patient.

### EEG

The frequent use of neurosedatives often prevented us from obtaining useful clinical information from the EEG. Indeed we used EEG mainly as a guide to deep neurosedation and to detect non-convulsive seizures and status epilepticus and monitor its response to the therapy. We think it is impossible to choose a priori a unique QEEG setting that would be able to detect the different significant events of a monitoring. On the contrary, it is necessary first to characterize the expected event in terms of its spectral content (i.e. delta increase, attenuation of fast frequencies) and, in a second step; to introduce the found parameters in a trend visualization that is so adapted to detect this particular event. Obviously, the event must always be identified on the basis of the raw EEG and the same holds true to check possible trend modifications.

In case of NCSE, seizure detection algorithms with bar representation can help the neuro-intensivist to monitor the efficacy of treatment (i.e. counting number of ictal activities per hour: Fig. 6). However, because of the extreme variability of ictal patterns, we believe that an expert raw EEG interpretation necessary not only to diagnose an ictal pattern but also to confirm the real disappearance of all ictal activity in response to therapy; indeed, its morphology and spectral content may have been modified by the therapy, thus making the initial QEEG representation obsolete.

### SEPs

SEPs were always monitorable despite the frequent use of high level of neurosedation. A classification of all possible drug-related SEP modifications is beyond the scope of this paper but we think that anyone who decides to perform continuous SEP monitoring should get the expertise to detect those SEP changes that are due to neurosedation. Consider for example the differential effect of a single bolus compared to a prolonged infusion of high doses of...
sedative. While a bolus mainly modifies the intermediate SEP components, prolonged infusion of high doses of sedatives may also modify early SEP components, whose latency progressively increases and amplitude progressively decreases. However, there are no general rules. Indeed, with propofol infusion, we have seldom observed an initial amplitude increase, followed by an amplitude reduction, of early SEP components (Fig. 3). More frequently, in case of an asymmetric SEP response, we also observed a different effect of sedatives on the affected hemisphere, compared to the non-affected one: in particular, during a total EEG suppression, there was a major decrease in SEP amplitude on the non-affected hemisphere, thereby decreasing the inter-hemispheric asymmetry. The original asymmetry recovered when sedatives were progressively reduced (Fig. 4).

To our opinion it is mandatory to monitor both hemispheres, independently of whether cortical SEPs are bilaterally well preserved or asymmetrical. Indeed, if SEP worsening is expected, this is likely to occur earlier on the more affected side, while a SEP changes on the better side will probably occur later on, only in a more advanced evolution of brain damage.

The ultimate purpose of a neurophysiologic monitoring system is to provide a display that can be interpreted, at least at first instance, also by personnel who is untrained in neurophysiology, such as the NICU staff; this can help to identify when an intervention is necessary to prevent further injury to the CNS [23]. If one aim of monitoring should be to allow non-experts recognizing abnormal trends rather than to interpret the raw waveforms, our experience and literature survey indicate that SEPs are more readily amenable to trend representation than EEG. Furthermore, since the automatic interpretation has always to be verified against the raw waveforms before proposing appropriate action, the simple waveform of raw SEPs renders them readily interpreted even by non-trained personnel, while raw EEG interpretation always requires a neurophysiologist. Moreover, SEP trends are based on two simple parameters (amplitude and latency) whose variations (amplitude decrease and/or latency increase) are independent of the physiopathology of brain damage. For CEEG, on the contrary, quantitative parameters differ as a function of the expected event. Because of the high variability in morphology, location, and duration of these events of interest, one single set of quantitative data reduction tools will not fit every need. This would force to calculate and represent many QEEG parameters at the same time, thereby complicating instead of simplifying the monitoring survey because of a too high number of monitored parameters and of the necessity to perform multi-parametric cliniconeurophysiologic correlations. In any case there would always be a need for frequent raw-EEG visualization and expert interpretation. Moreover there is not still any evidence of which are the best QEEG parameters for the NICU detection of ischemia, changes in reactivity, and development of focal changes. As an alternative to the use of many QEEG parameters, we suggest to associate continuous SEPs with CEEG, and to limit the use of QEEG to its proven indications (drug-related burst-suppression ratio, seizures-counter) [4]. The usefulness of SEP in monitoring the evolution of brain damage is proven by the widespread use of SEPs in IOM [7,8,20], and by the evidence that SEPs are the best predictors of outcome after severe brain injury [2]. Overall, we do not think that a continuous SEP monitoring in a comatose and sedated patient in NICU is technically more difficult and potentially less useful than in the operating room.

Conclusion

We think that continuous monitoring should be the point of arrival of a consolidated experience in the use of single neurophysiologic tests for a diagnostic and prognostic purpose in NICU. It is based on the neurointensivist’s knowledge of EEG/EP indications and limits and on the neurophysiologist’s knowledge of the physiopathology of ABI. Considering the necessity of a high involvement of both medical and technical staffs, not only in terms of monitoring performance but also in terms of personnel training, it would be useful to consider the possibility of one person who would be specifically dedicated for a part of his time, to implement monitoring in the NICU.

We believe that clinical neurophysiology has an important role for diagnosis and prognosis [1,2,10,21] in NICU. We agree with Hirsch [11] that it is nowadays difficult to ignore the monitoring of cerebral function in NICU. Indeed, it is hardly acceptable that a patient who has been monitored in the operating room does not benefit from an adequate monitoring in the NICU till the early stabilization of his neurological function. Our experience confirms the feasibility of a continuous EEG-SEP monitoring and encourages testing its clinical efficacy.

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