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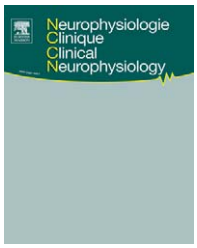

REVIEW/MISE AU POINT

EEG-NIRS in epilepsy in children and neonates

EEG-SPIR chez les patients épileptiques

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EEG ;
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Summary Coregistration of EEG-near infrared spectroscopy (NIRS) is a recent technique used to analyse changes in both electrical and local hemodynamic activities. Here, we describe some technical aspects of simultaneous EEG-NIRS signal acquisition focusing on recent EEG-NIRS sensors, notably the Electroptode®™. Advantages and disadvantages of simultaneous EEG-NIRS acquisition are discussed in comparison to other common techniques in epilepsy. Most important recent results are presented and discussed, notably those providing new insights into the mechanisms propelling neurons to synchronize, resulting in inter-critical spikes and different types of seizures.

Résumé L'enregistrement simultané en EEG-spectroscopie proche infrarouge (SPIR) est une technique récente qui permet l'analyse simultanée des modifications des activités cérébrales électriques et hémodynamiques locales. Nous décrivons certains aspects techniques de l'acquisition simultanée des signaux EEG-SPIR en insistant sur le développement récent de nouveaux capteurs EEG-SPIR, les Electroptodes®™. Nous comparons les avantages et les inconvénients de l'acquisition simultanée en EEG-SPIR des activités cérébrales par rapport aux autres techniques utilisées en routine pour l'évaluation des patients épileptiques. Les résultats récents les plus marquants sont discutés, notamment ceux qui permettent une nouvelle approche pour la compréhension des mécanismes qui participent à la mise en synchronie d'une population de neurones, aboutissant à l'élaboration de pointes intercritiques ou de différents types de crises.

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Introduction

EEG is the gold standard in the diagnosis of epilepsy. This is the technique that, together with clinical evaluation is at the origin of the classification of seizures and epileptic syndromes. Therefore, it is the reference tool in the management of epileptic patients. Due to its high temporal resolution, it allows analysing the electrical activity of neurons. Its principle is based on the activation of a large population of hypersynchronised neurons, mainly localized near the surface of the cortex. In the context of epilepsy, it reflects the disruption of neuronal activity that underlies this disease.

It is known that any neuronal activation produces hemodynamic changes and vice versa hemodynamic changes may cause changes in neuronal electrical activity.

This phenomenon of neurovascular coupling is the basis for the assumption that functional imaging techniques represent neural activity by capturing characteristic hemodynamic or metabolic activity during seizures (fMRI, PET, SEPCT). Many studies have been made in this regard, in particular to define more precisely the extent and location of neural structures, whose dysfunction is the cause of epilepsy semeiology. Most of this has been initiated to improve the management of patients with epilepsy as part of pre-surgical assessments. Different types of hemodynamic changes during seizures have been described, hyper-metabolism and hypo-metabolism, decrease and increase in cerebral flow and blood volume. Such combined analysis identified the ''default state'' in absence epilepsy using 3D representations of metabolic and hemodynamic changes related to electrical activity of neurons in the course of absence epilepsy.

Various studies have sought to assess the hemodynamic and/or electrical changes which precede either inter-critical spikes or seizures.

Further processing of EEG and fMRI signal have been performed in both partial and generalized epilepsy to highlight changes of complex local and long distance neural networks synchronization, which could cause the changes in hemodynamic and metabolic activities observed prior to seizures.

Recently, the studies of the team of Jean Gottman [18] combining EEG and fMRI have suggested the existence of hemodynamic changes prior to inter-critical spikes. Our study with animal models [29], which combined EEG and infrared spectroscopy, showed similar results. In addition, it provides information about changes in the concentration of both oxygenated and deoxygenated hemoglobin. This raises numerous questions about the mechanisms and structures involved in the emergence of spikes. It emphasizes a potential involvement of neural cells such as astrocytes, raising the question of their roles in the synchronization of neuronal populations.

All these results have mostly been obtained from older children and adults. But fMRI and PET and even more SPECT suffer from poor temporal resolution compared to EEG. In fact, in PET, it is mainly the inter-ictal periods that are analyzed and, in SPECT, it is often a single seizure only and rarely more in fMRI which provides the hemodynamic and metabolic information. Moreover, it is difficult with these techniques to assess the spatial and time course of hemodynamic changes during seizures and/or spikes. In this regard, the functional monitoring technique should have two important properties as: (1) it should not require immobilization of subject in a particular posture and; (2) it should be possible to have continuous concurrent recording with EEG for a long period. To our knowledge, presently only such technique is near infrared spectroscopy (NIRS). Therefore, we believe that NIRS has a particular importance in the monitoring and, hence, care of patients with epilepsy.

Indeed, there are numerous advantages of NIRS:

- it can be done at the bedside;
- no side effects are described so far and it is thus suitable for children and neonates;
- it is non-invasive (does not require injection of radioactive agent);
- it can be recorded and analyzed concurrently with EEG during long-term monitoring at the bedside;
- it allows the analysis of reduced hemoglobin as functional MRI;
- it provides analysis of oxygenated hemoglobin and total hemoglobin (and thus reflects changes in local blood volume);
- it has a high temporal resolution, as the EEG, more than necessary for complete analysis of physiological phenomenon, much better than the functional MRI, the PET or the SPECT;
- it does not require the immobilization of the child;
- it can be coupled to the analysis of changes in cardiorespiratory disorders, which may interact with the local cerebral hemodynamics.

It has also some disadvantages:

- it has a low spatial resolution, notably in-depth;
- it is sensitive to certain movements, which transmitted by the optical fibers induce artefacts;
- its implementation is not always easy, especially in older children, because of the hair.

NIRS is a technique currently being evaluated in the exploration of epilepsy. In 1977, F. Jöbsis [21] published the first in vivo study of NIRS in cats and humans.

The optical imaging NIRS is based on the absorption of light spectrum in the near infrared window (650 to 890 nm) by certain chromophores in living tissue. This particular NIRS window is the unique part of non-ionizing spectrum. In this window, light can penetrate over a significant depth (few centimetres) without getting significantly absorbed by background tissue constituents. Furthermore, it is of particular interest due to its highest and distinct sensitivity to oxygenated and reduced hemoglobin and to cytocrome C oxidase. Absorption refers to the process whereby the energy of the photon is absorbed by another entity causing the transition between two energy levels. As the absorption process is specific for the photon energy, the absorption of a chromophore depends on the wavelength of the photon. The main chromophores of living tissue are hemoglobin, cytochrome C oxidase, melanin and lipids.

Hemoglobin is a protein that has two stable states, reduced state [HBR] and oxidized state [HbO_2] and each has a different spectrum in the near infrared. Following is the basic idea behind NIRS for [HbO] and [HbR] computation.