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Exploring the capability of wireless near infrared spectroscopy as a portable seizure detection device for epilepsy patients

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ABSTRACT

Purpose: Near infrared spectroscopy (NIRS) has proved useful in measuring significant hemodynamic changes in the brain during epileptic seizures. The advance of NIRS-technology into wireless and portable devices raises the possibility of using the NIRS-technology for portable seizure detection.
Methods: This study used NIRS to measure changes in oxygenated (HbO), deoxygenated (HbR), and total hemoglobin (HbT) at left and right side of the frontal lobe in 33 patients with epilepsy undergoing long-term video-EEG monitoring. Fifteen patients had 34 focal seizures (20 temporal-, 11 frontal-, 2 parietal-lobe, one unspecific) recorded and analyzed with NIRS. Twelve parameters consisting of maximum increase and decrease changes of HbO, HbR and HbT during seizures (1 min before- to 3 min after seizure-onset) for left and right side, were compared with the patients' own non-seizure periods (a 2-h period and a 30-min exercise-period). In both non-seizure periods a 4 min moving windows with maximum overlapping were applied to find non-seizure maxima of the 12 parameters. Detection was defined as positive when seizure maximum change exceeded non-seizure maximum change.
Results: When analyzing the 12 parameters separately the positive seizure detection was in the range of 6–24%. The increase in hemodynamics was in general better at detecting seizures (15–24%) than the decrease in hemodynamics (6–18%) ($P = 0.02$).
Conclusion: NIRS did not seem to be a suitable technology for generic seizure detection given the device, settings, and methods used in this study. There are still several challenges to overcome before the NIRS-technology can be used as a home-monitoring seizure detection device.

1. Introduction

Near infrared spectroscopy (NIRS) is an evolving technology for continuous, non-invasive monitoring of hemodynamic changes in the brain [1,2]. Although the NIRS technology holds a disadvantage over BOLD-fMRI in spatial resolution and depths of measurement, NIRS is still superior to fMRI in temporal resolution and, importantly, gives the opportunity to measure the long-term hemodynamics in the brain even when patients are in motion [1]. Already in the beginning of the millennium NIRS proved to be a useful aid for lateralizing the seizure onset. Oxygenated hemoglobin (HbO) and saturation of the regional cerebral blood volume (rCBV) measured with NIRS, was shown to increase significantly in the seizure onset zone [3,4]. Recent research with NIRS furthermore revealed that the local hemodynamic changes during focal seizures quickly spread both extratemporal and contralateral in the brain [5,6]. Nguyen et al. reported significant changes of both oxy- and deoxygenated hemoglobin (HbO and HbR) in the frontal lobe both ipsi- and contralateral for temporal lobe seizures [5].

Prior research using NIRS in epilepsy have mainly focused on hemodynamic changes during seizures in regards to localizing focus, distinguishing seizure types, and spread of hemodynamic changes [3–7]. However, suggestions of using NIRS to predict or detect epileptic seizures have as of lately been proposed and also studied in a few cases [8–10]. Recently NIRS-devices with wireless connection have been introduced, which furthermore realize the

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possibility of using the technology as a portable home-monitoring epilepsy seizure detection or prediction device [11,12]. However, it still remains uncertain if the NIRS-measured hemodynamic changes seen during seizures are greater than (and thereby can be distinguished from) the hemodynamic changes that happens during other daily non-seizure periods including random movement and exercise, which is also known to alter the oxygenation in the prefrontal cortex [2].

The aim of this study was to test if standardized quantitative NIRS-measurement of the changes of oxygenated- (HbO), deoxygenated- (HbR) and total-hemoglobin (HbT) that occur in the frontal lobe of the brain during seizures could be used as a biomarker for seizure detection. In order to test this we compared the hemodynamic changes during seizures from each patient with selected control non-seizure periods of both exercise and non-exercise periods from the same patient.

2. Methods

2.1. Patients

Thirty-three patients enrolled in long term video-EEG monitoring (LTM) at the epilepsy monitoring unit (EMU) in either Aarhus University Hospital or Danish Epilepsy Center in Dianalund for diagnostic or surgical evaluation of epilepsy were recruited to participate in the study. Fifteen (age: 20–58, med: 39) of the 33 patients had one or more epileptic seizures with frontal NIRS-recording during the period of hospitalization. If a patient had more than six NIRS-recorded seizures, only the first six seizures were chosen. A total of 34 focal seizures (31 complex partial, three simple partial) were recorded and analyzed with NIRS. All patients were instructed to perform an exercise-bike session with stepwise pulse increase of 110 beats/min for 2 min, 140 beats/min for 2 min and all-out maximum for 3 min. This was used as one of the sample control periods. One patient did not complete the test because of knee-injuries (Patient 15).

2.2. Equipment

Two PortaLite wireless near infrared spectroscopy devices (Artinis Medical Systems B.V., PW Elst, Holland) were used for all recordings. The devices were placed on each site of the forehead just below the hairline. On the left side this was between the Fp1 and F7 EEG-electrode and on the right side between the Fp2 and F8 EEG-electrode in the 10–20 EEG electrode placement system. Black cloths were attached on top of the EEG-cap to ensure that no external light from other than the NIRS-device would interfere with the NIRS signal (see Fig. 1). Each device has three light source emitting diodes at 30, 35 and 40 mm from the detector. The diodes emit near infrared light at wavelengths of 760 and 850 nm to continuously measure the hemoglobin changes using the modified Lambert–Beer Law method [13]. To derive quantitative concentration changes from measurements of light attenuation, the optical path length has to be known. This is obtained by multiplying the source/detector separation by a laboratory measured differential path length factor (DPF) which accounts for the increased distance the light travels due to scattering. As DPF increases with age a specific DPF was calculated for each patient using the formula: DPF = 4.99 + 0.067 (age^0.814), (if age $>$ 50 the age was set to 50) [14]. Oxy-, deoxy- and total hemoglobin concentration changes in units of micromoles pr. liter was computed with a sampling frequency of 10 Hz for each of the three diodes. The recorded data were transmitted online via Bluetooth from the battery-driven PortaLite device to a PC-laptop and obtained in the OxySoft program (versions 2.1.6 or 3.0.53). From both devices the mean value of the three estimates (one from each diode) of HbO, HbR and HbT was computed for further analyses. Timestamps was manually inserted during the recordings in the OxySoft program to synchronize timing with the video-EEG recordings. The batteries of the wireless NIRS-device could hold 8–10 h thus had to be changed three times every day.

2.3. Signal analyses

In order to even out the heart pulse-effect of the hemodynamic readings and even out short sudden artifacts of the measurements the sample frequency of 10 Hz was down-sampled to 0.25 Hz using simple moving average method. We found it reliable to down-sample the recordings to 0.25 Hz, as the physiological interpretation of the signal was unaffected because the seizures with hemodynamic responses generally showed sequences from nadir to peak and vice versa of at least 20 s, which also is in alignment with other NIRS-studies of epileptic seizures [3,4].

In order to quantify and compute the changes during seizures and test if they could be used as a possible seizure detection biomarker, we developed a custom made program to find maximum increases and decreases of HbO, HbR and HbT during seizures and non-seizure periods. A 4 min window from 1 min before seizure-onset to 3 min after seizure-onset was selected for all seizures and the maximum increases and decreases of HbO, HbR and HbT from both recording sides were computed. Each patient had these maxima compared with two non-seizure periods of (1) 30 min period in which the patient performed a bike exercise-test, (2) 2-h non-seizure period recorded from 3 to 1 h before the first analyzed seizure of the patient. If the 2-h non-seizure period contained the bike-exercise test or any notable artifacts caused by movement of the NIRS device or battery change of the wireless NIRS-device, the first previous 2-h period with none of the above artifacts was chosen instead. For both of the non-seizure periods a 4 min rectangular moving window with maximum overlapping

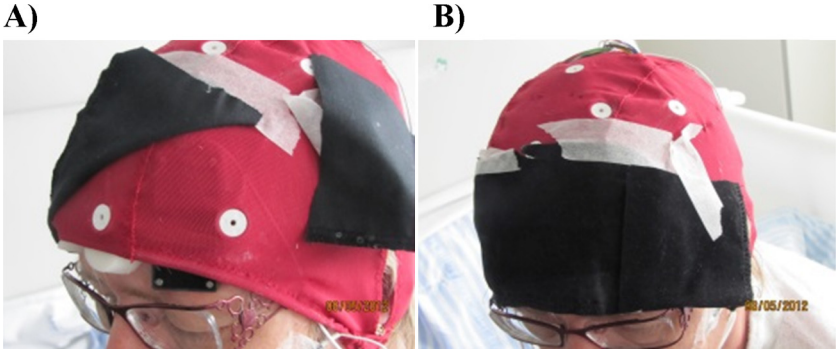

Fig. 1. (A) Left NIRS-device was placed between EEG-electrode F1 and F7. (B) Black cloths covered the NIRS and surrounding area from external light.