Clinical Neurophysiology 128 (2017) 1524–1531

Contents lists available at ScienceDirect

Clinical Neurophysiology

journal homepage: www.elsevier.com/locate/clinph

Reduced electrode arrays for the automated detection of rhythmic and periodic patterns in the intensive care unit: Frequently tried, frequently failed?

J. Herta [a,*], J. Koren [b], F. Fürbass [c], M. Hartmann [c], A. Gruber [a], C. Baumgartner [b,d]

[a] Department of Neurosurgery, Medical University of Vienna, Vienna, Austria
[b] Karl Landsteiner Institute for Clinical Epilepsy Research and Cognitive Neurology, 2nd Neurological Department, General Hospital Hietzing with Neurological Center Rosenhuegel, Vienna, Austria
[c] AIT Austrian Institute of Technology GmbH, Digital Safety & Security Department, Vienna, Austria
[d] Department of Epileptology and Clinical Neurophysiology, Sigmund Freud University, Vienna, Austria

See Editorial, pages 1519–1521

ARTICLE INFO

Article history:
Accepted 18 April 2017
Available online 26 April 2017

Keywords:
Epileptic seizure detection
Prospective multi-center study
Continuous EEG
Intensive care unit
Computer algorithm

HIGHLIGHTS

- First study that systematically evaluates the effect of automated electrode reduction on pattern detection.
- Effect of electrode reduction on pattern detection sensitivity was evaluated by a computer algorithm.
- Guidance which reduced EEG array may offer the highest detection results in specific situations.

ABSTRACT

Objective: To investigate the effect of systematic electrode reduction from a common 10-20 EEG system on pattern detection sensitivity (SEN).

Methods: Two reviewers rated 17130 one-minute segments of 83 prospectively recorded cEEGs according to the ACNS standardized critical care EEG terminology (CCET), including burst suppression patterns (BS) and unequivocal electrographic seizures. Consensus annotations between reviewers were used as a gold standard to determine pattern detection SEN and specificity (SPE) of a computational algorithm (baseline, 19 electrodes). Electrodes were than reduced one by one in four different variations. SENs and SPEs were calculated to determine the most beneficial assembly with respect to the number and location of electrodes.

Results: High automated baseline SENs (84.99–93.39%) and SPEs (90.05–95.6%) were achieved for all patterns. Best overall results in detecting BS and CCET patterns were found using the "hairline + vertex" montage. While the "forehead + behind ear" montage showed an advantage in detecting ictal patterns, reaching a 15% drop of SEN with 10 electrodes, all montages could detect BS sufficiently if at least nine electrodes were available.

Conclusion: For the first time an automated approach was used to systematically evaluate the effect of electrode reduction on pattern detection SEN in cEEG.

Significance: Prediction of the expected detection SEN of specific EEG patterns with reduced EEG montages in ICU patients.

Abbreviations: ACNS, American clinical neurophysiology society; BAM, "Banana" montage; BS, burst suppression patterns; CCET, American clinical neurophysiology society standardized critical care EEG terminology; cEEG, continuous electroencephalography; CRM, "Crown" montage; D15, drop of detection sensitivity of more than 15%; EEG, electroencephalography; FOM, "Forehead + behind ear" montage; HAM, "Hairline + vertex" montage; ICU,, intensive care unit; NCS,, nonconvulsive seizures; NOPAT, no pattern; PD, periodic discharge; RAA, rhythmic alpha activity; RDA, rhythmic delta activity; RTA, rhythmic theta activity; SEN, sensitivity; SPE, specificity.

* Corresponding author at: Medical University of Vienna, Department of Neurosurgery, Währinger Gürtel 18-20, 1090 Vienna, Austria. Fax: +43 01 40400 45660.
E-mail address: johannes.herta@meduniwien.ac.at (J. Herta).

http://dx.doi.org/10.1016/j.clinph.2017.04.012

1. Introduction

Continuous EEG (cEEG) allows noninvasive monitoring of brain function with a high temporal resolution. Especially in the intensive care unit (ICU) it can add important information where conclusions from clinical examination may often be limited. For many applications, such as the detection of nonconvulsive seizures (NCS), the guidance of seizure treatment and the management of pharmacological induced coma, cEEG is considered the primary diagnostic tool (Jordan, 1999; Friedman et al., 2009). But even with an increased awareness of seizures in the ICU and huge advancements in computer technology, the use of EEG remains limited in everyday clinical practice. This is mainly due to the significant efforts associated with EEG. Besides the negligible costs of the recording device, personnel resources represent the major limiting factor. On the one hand, specially trained, 24-h available physicians are needed to review several hours of EEG. On the other hand, EEG technician must attach and maintain the electrode setup. In an ICU setting a trained EEG technician needs about 30–45 min to setup 19 cup electrodes. But collodion will dry out within the first six hours and needs accurate maintenance (Young et al., 2006). To increase availability and simplify the EEG setup, several studies assessed the possibility to work with a reduced number of electrodes (Bridgers and Ebersole, 1988; Foldvary et al., 2000; Tekgul et al., 2005; Kolls and Husain, 2007; Shellhaas and Clancy, 2007; Wusthoff et al., 2009; Young et al., 2009; Karakis et al., 2010; Nitzschke et al., 2011; Rubin et al., 2014; Tanner et al., 2014; Brenner et al., 2015; Lepola et al., 2015; Muraja-Murro et al., 2015).

A reduced electrode setup may have more potential benefits than just time saving. It can come in handy for patients where proper lead placement due to head wounds or drains is not possible. Furthermore, it may encourage physicians to use cEEG more frequently and consolidate acceptance among nursing staff. Previous studies reported frequent delays in the diagnosis of NCS (Dunne et al., 1987). Since mortality increases with seizure duration (Young et al., 1996) a reduced and easy applicable electrode setup should facilitate prompt diagnosis of NCS and benefit critical care patients.

Until now various approaches of electrode reduction have been published, that can be roughly summarized into three groups. Group-one tried to use a single-channel EEG (e.g. C3, C4). This was mainly used in neonates where most of seizures originate from the central midline (Schultz et al., 1992; Shellhaas and Clancy, 2007; Wusthoff et al., 2009). Group-two tried to cover as much of the scalp as possible, maintaining the 10–20 system based locations of electrodes (e.g. F3, F4, T7, Cz, T8, O1, O2) (Foldvary et al., 2000; Tekgul et al., 2005; Kolls and Husain, 2007; Karakis et al., 2010; Rubin et al., 2014; Lepola et al., 2015). Group-three's main interest was to develop an electrode setup which was easy to use and fast to apply in emergency cases (Bridgers and Ebersole, 1988; Young et al., 2009; Brenner et al., 2015; Muraja-Murro et al., 2015). In this setting it should be possible to place electrodes, without the help of an EEG technician, under the hairline on the forehead and behind the ear (e.g. Fp2, Fp1, F8, F7, Sp1, Sp2, T9, T10). Concerning seizure detection, nearly all major studies showed a tendency towards poor sensitivity (SEN). The common denominator of all these studies was to predefine a reduced electrode setup and compare its seizure detection rates with that of a standard 10–20 system.

In the present study, we reduced the electrodes of the International 10–20 EEG system systematically one by one, which to the best of our knowledge has never been done before. A computational algorithm assessed each reduction step. Four different variations of final electrode arrays, mainly derived from previously published reduced EEG montages were evaluated. Detection sensitivities (SEN) and specificities (SPE) for unequivocal electrographic seizures (spike-wave > 3 Hz, evolving discharges > 4 Hz), patterns defined by the ACNS Standardized Critical Care EEG Terminology (CCET) and burst suppression patterns (BS) were calculated (Hirsch et al., 2013). The aim of the study was to observe and illustrate the change in detection SEN and SPE for every reduced electrode and pattern of interest, to allow an individual assessment in cases where reduced setups are needed.

2. Methods

2.1. Dataset

A dataset of 92 prospectively recorded cEEGs in a neurological and a neurosurgical ICU (Neurological Center Rosenhuegel, General Hospital Vienna) was used. EEGs were recorded with a Micromed EEG recording system (SystemPLUS Evolution 1.04.95, Micromed S.p.A., Veneto, Italy) using the International 10–20 electrode system with a sampling rate of 256 Hz. Inclusion criteria for this study were 1) recordings longer than 24 h and 2) artefact-free recordings from a full set of 19 electrodes for more than 90% of the overall recording time. 7 EEGs were recorded with less than 19 electrodes. Another 2 patients had a recording time under 24 h. This left 83 patients for the study (6733 h, mean individual recording duration 73 h). Two types of electrodes were used for recordings: gold cup electrodes (Genuine Grass Gold Disc electrodes) and conductive plastic cup electrodes (Ives EEG Solutions). Research was prior approved by the institutional ethics committee.

2.2. NeuroTrend

NeuroTrend is a computational method that facilitates screening of long-term EEGs. It automatically detects rhythmic and periodic patterns in surface EEG and displays their localization and frequency in a graphical user interface. Results are visualized with a focus on data and time compression. Therefore, hours of cEEG can be compressed and displayed on a single screen. The definition of rhythmic and periodic EEG patterns follows the guidelines of CCET adding unequivocal electrographic seizures including generalized spike-wave discharges at 3 Hz or faster as well as evolving discharges that reach frequencies of more than 4 Hz and BS (Hirsch et al., 2013). Fürbass et al. (Fürbass et al., 2015) described the technical background of the algorithm, while Herta et al. (Herta et al., 2015) recently performed a validation of NeuroTrend. For this study a newer version of the algorithm was used. Especially RDA, which showed a high rate of false positive detections due to general slowing in the past, improved in terms of detection SEN and SPE as seen in Table 1. NeuroTrend is part of the encevis software package, in this work version V1.3 of encevis was used (http://www.encevis.com).

2.3. Data processing and statistical methods

The first minute of each hour of the raw cEEG recordings were identified and reviewed by two clinical neurophysiologists. In these segments the reviewers could assign one of four possible labels (1) periodic discharge (PD), (2) rhythmic delta activity (RDA), (3) ictal group (4) burst suppression patterns (BS). In each one-minute EEG segment multiple annotations could be made if they occurred consecutively. If no annotation was made the specific segment was labeled no pattern (NOPAT). Periodic and rhythmic delta patterns were rated according to the CCET guidelines. The ictal group included unequivocal electrographic seizures including generalized spike-and-wave discharges at 3 Hz or faster as well as evolving discharges that reach frequencies of more than 4 Hz.