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Rhythmic and periodic EEG patterns of 'ictal–interictal uncertainty' in critically ill neurological patients

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HIGHLIGHTS

- Rhythmic and periodic EEG patterns of 'ictal–interictal uncertainty' (RPPIIIU) occurred three times more frequently than electrographic seizures.
- RPPIIIU were highly predictive for electrographic seizures.
- RPPIIIU might represent interictal rather than ictal EEG patterns in patients with co-occurrence of electrographic seizures.

ABSTRACT

Objectives: To study periodic and rhythmic EEG patterns classified according to Standardized Critical Care EEG Terminology (SCCET) of the American Clinical Neurophysiology Society and their relationship to electrographic seizures.
Methods: We classified 655 routine EEGs in 371 consecutive critically ill neurological patients into (1) normal EEGs or EEGs with non-specific abnormalities or interictal epileptiform discharges, (2) EEGs containing unequivocal ictal EEG patterns, and (3) EEGs showing rhythmic and periodic EEG patterns of 'ictal–interictal uncertainty' (RPPIIIU) according to SCCET.
Results: 313 patients (84.4%) showed normal EEGs, non-specific or interictal abnormalities, 14 patients (3.8%) had EEGs with at least one electrographic seizure, and 44 patients (11.8%) at least one EEG containing RPPIIIU, but no EEG with electrographic seizures. Electrographic seizures occurred in 11 of 55 patients (20%) with RPPIIIU, but only in 3 of 316 patients (0.9%) without RPPIIIU ($p \leqslant 0.001$). Conversely, we observed RPPIIIU in 11 of 14 patients (78.6%) with electrographic seizures, but only in 44 of 357 patients (12.3%) without electrographic seizures ($p \leqslant 0.001$).
Conclusions: On routine-EEG in critically ill neurological patients RPPIIIU occur 3 times more frequently than electrographic seizures and are highly predictive for electrographic seizures.
Significance: RPPIIIU can serve as an indication for continuous EEG recordings.

Abbreviations: ACNS, American Clinical Neurophysiology Society; BI, bilateral independent; BiPLEDs, bilateral independent periodic lateralized epileptiform discharges; cEEG, continuous electroencephalography; CNS, central nervous system; EEG, electroencephalography; G, generalized; GCS, Glasgow Coma Scale; GPEDs, generalized periodic epileptiform discharges; IIC, ictal–interictal continuum; IMC, intermediate care unit; L, lateralized; NCS, nonconvulsive seizures; NCSE, nonconvulsive status epilepticus; PDs, periodic discharges; PEDs, periodic epileptiform discharges; PLEDs, periodic lateralized epileptiform discharges; RDA, rhythmic delta activity; RPPIIIU, rhythmic and periodic EEG patterns of 'ictal–interictal uncertainty'; SCCET, Standardized Critical Care EEG Terminology; SW, spike-and-wave complexes.

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1. Introduction

Periodic discharges, fluctuating rhythmic patterns and combinations thereof frequently occur in critically ill neurological patients and therefore were one of the main issues of the revised version for a Standardized Critical Care EEG Terminology (SCCET) proposed by the American Clinical Neurophysiology Society (ACNS) (Hirsch et al., 2013). Due to their equivocal nature the use of 'ictal', 'interictal' and 'epileptiform' was avoided (Hirsch et al., 2013). Specifically it is unclear whether these patterns correspond to an ictal state or rather represent interictal EEG correlates of severe brain damage, which patterns should to be treated and finally whether successful treatment of EEG improves outcome (Young et al., 1996; Chong and Hirsch, 2005; Kaplan, 2007; Bauer and Trinka, 2010; Holtkamp and Meierkord, 2011; Sutter and Kaplan, 2012; Hirsch et al., 2013). Periodic discharges and fluctuating rhythmic patterns have to be distinguished from EEG patterns which clearly represent ongoing EEG seizure activity indicating nonconvulsive seizures (NCS) and nonconvulsive status epilepticus (NCSE) (Chong and Hirsch, 2005; Beniczky et al., 2013; Hirsch et al., 2013).

Many excellent papers have reviewed EEG patterns in critically ill patients (Young et al., 1996; DeLorenzo et al., 1998; Jordan, 1999; Towne et al., 2000; Dennis et al., 2002; Husain et al., 2003; Vespa et al., 2003; Claassen et al., 2004; Alroughani et al., 2009; Fernandez-Torre et al., 2012; Foreman et al., 2012; Claassen et al., 2013; Crepeau et al., 2013; Gaspard et al., 2013) or have focused on specific patterns in selected patient groups (Reiher et al., 1991; Foreman et al., 2012; Crepeau et al., 2013; Gaspard et al., 2013). However, systematic studies on the incidence of unequivocal ictal EEG patterns and periodic discharges as well as fluctuating rhythmic patterns classified according to SCCET including their relationship to electrographic seizures are scarce (Crepeau et al., 2013).

We therefore systematically assessed incidence and features of clearly defined EEG patterns in a large cohort of critically ill neurological patients. Specifically we distinguished (1) normal EEGs and EEGs containing non-specific abnormalities or interictal epileptiform discharges according to the glossary of the International Federation of Clinical Neurophysiology (Noachtar et al., 1999), (2) rhythmic and periodic EEG patterns defined according to SCCET (Hirsch et al., 2013) and (3) clearly defined ictal EEG patterns (Young et al., 1996; Chong and Hirsch, 2005). Finally, we studied the co-occurrence of rhythmic and periodic EEG patterns and their relation to electrographic seizures.

2. Methods

2.1. Patients

We reviewed all routine EEGs performed in our neurological intermediate care unit (IMC) between October 2009 and October 2013. Indications for EEG included acute seizures prior to admission, overt seizures after admission, and clinical suspicion of nonconvulsive seizures or nonconvulsive status epilepticus.

2.2. EEG analysis

Two board-certified electroencephalographers (JK and SP), reviewed all EEG data independently and classified them according to the glossary of the International Federation of Clinical Neurophysiology (Noachtar et al., 1999), the American Clinical Neurophysiology Society Standardized Critical Care EEG Terminology (SCCET) (Hirsch et al., 2013) and criteria for nonconvulsive seizures proposed by Chong and Hirsch (2005). Disagreement over diagnosis of certain EEG patterns was solved by involving a third board-certified electroencephalographer (CB). Using this fashion, we obtained a consensus agreement for every EEG recording. Specifically we categorized EEGs as follows:

- EEG group I
  - Normal EEGs with no interictal or ictal epileptiform discharges and no non-specific EEG abnormalities.
  - EEGs showing non-specific EEG abnormalities (including regional and/or generalized intermittent slowing including frontal intermittent rhythmical delta activity – FIRDA; regional and/or generalized continuous slowing).
  - EEGs showing interictal epileptiform discharges (including regional and/or generalized spikes, spike-wave discharges and/or polyspikes).
- EEG group II
  EEGs showing rhythmic and periodic EEG patterns defined according to SCCET (Hirsch et al., 2013) including periodic discharges (PDs), rhythmic delta activity (RDA), and repetitive spike-and-wave complexes (SW) not fulfilling the criteria to qualify as ictal EEG patterns defined below. We named these EEG findings rhythmic and periodic patterns of 'ictal–interictal uncertainty' (RPPIIIU), i.e. EEG patterns which cannot be ascribed to the interictal or ictal state with certainty.
- EEG group III
  EEGs showing criteria for nonconvulsive seizures initially proposed by Young et al. (1996) and modified by Chong and Hirsch (2005): any pattern lasting at least 10 s satisfying any one of the following 3 primary criteria: 1. Repetitive generalized or focal spikes, sharp-waves, spike-and-wave or sharp-and-slow wave complexes at $\geqslant$3/s. 2. Repetitive generalized or focal spikes, sharp waves, spike-and-wave or sharp-and-slow wave complexes at <3/s and the secondary criterion. 3. Sequential rhythmic, periodic, or quasi-periodic waves at $\geqslant$1/s and unequivocal evolution in location, frequency and/or morphology. The secondary criterion was defined as significant improvement in clinical state or appearance of previously-absent normal EEG patterns temporally coupled to acute administration of a rapidly-acting antiepileptic drug.

EEG group II patterns were further analyzed according to the following SCCET criteria: (1) location (Main Term 1), (2) morphology, i.e. PDs, RDA and SW (Main Term 2), (3) frequency (Modifier 3) and (4) Plus (+) (Modifier 10) (Hirsch et al., 2013).

Based on these EEG classifications patients were assigned to one of the following three groups.

- Patient group A – ('interictal group'): patients with exclusively EEG group I recordings.
- Patient group B – ('borderland group'): patients with at least one EEG group II recording, but no EEG group III recording.
- Patient group C – ('ictal group'): patients with at least one EEG group III recording.

2.3. Statistical analysis

Statistical analysis was performed using the commercially available statistical software (IBM SPSS 19.0), quantpsy.org (interactive calculation tool for chi-square tests of goodness of fit and independence) (Preacher, accessed in March 2015) and Microsoft Office Excel 2007. Differences between patient groups and EEG patterns were calculated using chi-square test (Yates' correction was used if expected frequencies less than 5 were calculated), Kruskal–Wallis test or Mann–Whitney U test because data were not normally distributed. Significance level for all statistical tests was set at $p < 0.05$.

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