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BRIEF COMMUNICATION

Detection of generalized tonic–clonic seizures by a wireless wrist accelerometer: A prospective, multicenter study

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Summary

Our objective was to assess the clinical reliability of a wrist-worn, wireless accelerometer sensor for detecting generalized tonic–clonic seizures (GTCS). Seventy-three consecutive patients (age 6–68 years; median 37 years) at risk of having GTCS and who were admitted to the long-term video–electroencephalography (EEG) monitoring unit (LTM) were recruited in three centers. The reference standard was considered the seizure time points identified by experienced clinical neurophysiologists, based on the video-EEG recordings and blinded to the accelerometer sensor data. Seizure time points detected real-time by the sensor were compared with the reference standard. Patients were monitored for 17–171 h (mean 66.8; total 4,878). Thirty-nine GTCS were recorded in 20 patients. The device detected 35 seizures (89.7%). In 16 patients all seizures were detected. In three patients more than two thirds of the seizures were detected. The mean of the sensitivity calculated for each patient was 91%. The mean detection latency measured from the start of the focal seizure preceding the secondarily GTCS was 55 s (95% confidence interval [CI] 38–73 s). The rate of false alarms was 0.2/day. Our results suggest that the wireless wrist accelerometer sensor detects GTCS with high sensitivity and specificity. Patients with GTCS have an increased risk for injuries related to seizures and for sudden unexpected death in epilepsy (SUDEP), and many nocturnal seizures remain undetected in unattended patients. A portable automatic seizure detection device will be an important tool for helping these patients.

KEY WORDS: Detection latency, False detection rate, Real-time, Sensitivity.

Generalized tonic–clonic seizures (GTCS), especially when unattended, are associated with an increased risk of injuries, and for sudden unexpected death in epilepsy (SUDEP) (Lhatoo et al., 2001; Tomson et al., 2004; Hesdorffer et al., 2011, 2012). Although several electroencephalography (EEG)–based seizure detection algorithms are available, and implemented in many inpatient epilepsy monitoring units, only a few patients are willing to wear EEG electrodes for signal acquisition on a long-term basis (Schulze-Bonhage et al., 2010).

Previous exploratory studies on the detection of convulsive seizures based on accelerometry signals alone (Nijsen et al., 2005; Becq et al., 2007; Kramer et al., 2011; Schulc et al., 2011) or in combination with other modalities (Conradsen et al., 2010; Poh et al., 2012) showed promising preliminary results. However, all of these studies used algorithms that were optimized post hoc for the offline detection of the seizures in the recorded data.

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Our aim was to assess the clinical reliability of a commercially available, wireless, wrist-worn seizure detection sensor (Epi-Care Free), based on real-time analysis of accelerometry signals, using a prospective, multicenter, controlled study design.

Methods

Seventy-three consecutive patients (39 male; age 6–68 years, median 37 years), at risk of having GTCS, admitted to long-term video-EEG monitoring for diagnostic reasons or for presurgical evaluation were recruited in three centers: Danish Epilepsy Center (27 patients), Bethel Epilepsy Center (28 patients), and Rigshospitalet University Hospital (18 patients). The study was approved by the local ethics committees, and the patients (or their caregivers) provided written, informed consent. The total time of monitoring and data analysis was 4,878 h (range 17–171, mean 66.8, median 72). The data of the 73 patients are summarized in Table S1.

Patients were not confined to bed, and they were encouraged to move as much as possible. In one center, patients could move freely in their room and also interact with other patients in the living room, dining room, and kitchen.

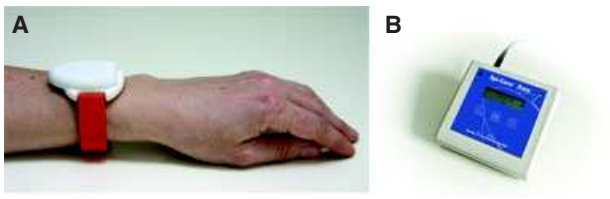

Figure 1.
(**A**) The wrist-worn accelerometry device. (**B**) The control unit.
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Patients could also play games involving motor activities (for example, computer games with whole body motion) if they wished to do so.

The seizure detection device (Epi-Care Free) had been developed by Danish Care Technology ApS (Sorø, Denmark). It resembles a wristwatch (Fig. 1A). It contains the three-axis acceleration transducer (sensor), a microprocessor, and a rechargeable battery. The sensor measures the acceleration of any movement in the wrist, whether this was in the x-, y-, or z-direction. The device has two-way wireless communication to a table placed or portable control unit (Fig. 1B). The sensor was to be used continuously, with a recharge of the built-in battery once every 24 h. An example of actual measurements for a patient is shown in Fig. 2.

If historical data on seizure semiology suggested an asymmetric involvement of upper limbs, the sensor was placed on the arm where convulsions were more pronounced or occurred earlier. Otherwise the sensor was placed on the nondominant arm. Patients were instructed to brush their teeth with the other arm, as previous exploratory measurements showed that this physiologic activity can mimic the clonic phase of the GTCS.

A predefined, generic convulsive seizure detection algorithm was used for all monitoring/detections. This was based on precise acceleration measurements of the patients' wrist (Data S1). Real-time calculations determined whether movements were seizure-like or normal. High values were given to seizure-like movements and alarm was triggered at a fixed threshold. The algorithm was fully automatic; no device settings or postprocessing was carried out.

The reference standard was considered the seizure time identified by experienced clinical neurophysiologists, based on the video-EEG recordings (Alving & Beniczky, 2009) and blinded to the accelerometer sensor data. Real-time seizure-onset detection by the sensor was compared to the timing of the reference standard. The automatic seizure detection process and logging of the detected time points was blinded to the clinical evaluation of the seizure, and to the clinical data of the patient. On its turn the clinical evaluation of seizure time points was blinded to the results of the device.

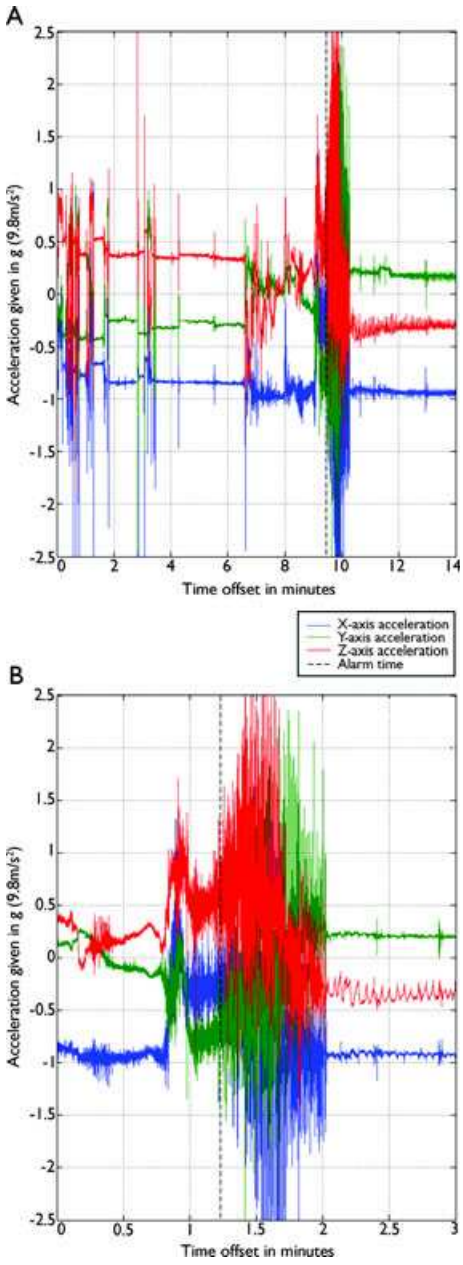

Figure 2.
Signals from the accelerometer: x-axis in blue, y-axis green, and z-axis in red. (**A**) At the end of the time epoch, a seizure is recorded; the first part of this time window contains physiologic (nonseizure) movements; the time of automatic seizure detection is indicated by the vertical line. (**B**) Focused on the measurements during this seizure.
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Results

Thirty-nine secondarily GTCS (one to five seizures/patient; mean 1.95) were recorded in 20 patients (mean age 37.3 years, range 13–63 years). The wireless wrist

accelerometer correctly detected 35 seizures (89.7%). The mean sensitivity per patient (with seizure) was 91% (95% confidence interval [CI] 80–100%). In 16 patients all seizures were detected. In three patients more than two thirds of the seizures were detected. Seizure was not detected at all in one patient who had only one seizure.

Twenty-eight seizures occurred during sleep and eleven seizures occurred when the patient was awake. The device had a similar accuracy for detecting nocturnal and daytime seizures: it detected 25 seizures during sleep (89%) and 10 seizures where the patient was awake (91%).

After evaluating the accuracy of the device, we retrospectively reviewed the four seizures that were not detected. The common feature in these seizures was, that an external, mechanical impediment restricted the movements of the arm where the sensor was placed: in two seizures the nurses were holding the arm of the patient, in an attempt to prevent injuries; in one seizure the arm movement was restricted by the blanket; in one case the patient was lying on the arm where the sensor was placed. Thus in only 2 (5%) of the 39 seizures did the sensors fail to detect a potentially undiscovered seizure.

The mean detection latency as measured from the start of the secondarily generalized phase was 33 s, and measured from the start of the focal seizure was 55 s (95% CI 38–73 s).

Totally 40 false alarms were recorded in 16 of the 73 patients. The rate of false alarms was 0.2/day (0.0082/h). In two patients six false alarms occurred when they brushed their teeth with the arm where the sensor was placed. Thirty-four false alarms occurred during voluntary rhythmic movements of the arms (playing cards, playing backgammon, and winding up the cable of the amplifier).

One hundred forty-nine seizures other than GTCS were recorded (simple partial, 37; complex partial/psychomotor, 31; focal tonic, 6; hypermotor, 6; absence, 1; myoclonus, 60; psychogenic nonepileptic seizure, 8). None of them triggered an alarm.

Device deficiency was recorded 15 times. Only one event led to the termination of the recording. This occurred in the first patient and was due to a technical error that subsequently was corrected and has not occurred afterward.

Another technical error led to a transient interruption of the recording. However, this was rapidly corrected and the recording was continued. Eleven events were caused by battery failure (it discharged in shorter time than 24 h). During the study, all measured data were transmitted by Bluetooth connection to a computer, and this demands more energy. In the commercially available product, only the alarm triggers are transmitted to the control unit, which considerably decreases the energy consumption.

Side effect was only recorded in one patient: the device triggered a mild allergic reaction on the skin, following the monitoring.

Discussion

In this prospective, multicenter study we showed that a commercially available wireless wrist accelerometer sensor detects GTCS with a high sensitivity (90%) and a low rate of false alarms (0.2/day). The predefined algorithm was sufficiently simple to allow real-time analysis of the accelerometry signals and to detect GTCS. It also proved to be robust as the generic algorithm did not need any optimization, postprocessing, or adjustment of the setting to the individual patient.

The seizure-detection device was user friendly. All patients or caregivers could easily handle this device, which resembles a wristwatch.

Although patients were encouraged to move freely as much as possible during the video-EEG monitoring, the amount of physiologic movements in this setting might be less than in the patients' home. Further follow-up, open studies in an outpatient setting are needed to elucidate this.

Once a seizure is real-time detected by the algorithm, the control unit triggers an alarm calling for help. In addition, the time points of the detected seizures are logged, so that the physicians can obtain an objective seizure diary. As many seizures (especially the nocturnal ones) remain unobserved in unattended patients, the automatic seizure detection system could provide objective data for adjustment of the therapy and even improve the quality of outcome measures of therapeutic studies. The alarm sent to the caretakers allows early intervention, a prerequisite and first step for a successful prevention of SUDEP in the future. However this has to be investigated further in a prospective, open study on a large number of patients, in an ambulatory setting.

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Disclosure

The authors have no conflicts of interest. We confirm that we have read the Journal's position on issues involved in ethical publication and affirm that this report is consistent with those guidelines.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Data S1. Development of the wireless accelerometer device.

Table S1. Data of the 73 included patients.