Background and Purpose—Guidelines recommend continuous ECG monitoring in patients with cerebrovascular events. Studies on intensive care units (ICU) demonstrated high sensitivity but high rates of false alarms of monitoring systems resulting in desensitization of medical personnel potentially endangering patient safety. Data on patients with acute stroke are lacking.

Methods—One-hundred fifty-one consecutive patients with acute cerebrovascular events were prospectively included. Automatically identified arrhythmia events were analyzed by manual ECG analysis. Muting of alarms was registered. Sensitivity was evaluated by beat-to-beat analysis of the entire recorded ECG data in a subset of patients. Ethics approval was obtained by University of Erlangen-Nuremberg.

Results—A total of 4809.5 hours of ECG registration and 22,509 alarms were analyzed. The automated detection algorithm missed no events but the overall rate of false alarms was 27.4%. Only 0.6% of all alarms indicated acute life-threatening events and 91.4% of these alarms were incorrect. Transient muting of acoustic alarms was observed in 20.5% patients.

Conclusions—Continuous ECG monitoring using automated arrhythmia detection is highly sensitive in acute stroke. However, high rates of false alarms and alarms without direct therapeutic consequence cause desensitization of personnel. Therefore, acoustic alarms may be limited to life-threatening events but standardized manual evaluation of all alarms should complement automated systems to identify clinically relevant arrhythmias. (Stroke. 2015;46:560-563. DOI: 10.1161/STROKEAHA.114.007892.)

Key Words: arrhythmia ■ electrocardiography ■ monitoring ■ stroke
manually analyzed. For sensitivity analysis, complete ECG data were reviewed beat-to-beat in a subset of patients (n=57). Cardiac diagnostics and therapy were initiated as appropriate.

Statistical Analysis
Data were processed using SPSS 21.0. Shapiro–Wilk test was applied to test for normality. Data are presented as mean/SD or median/interquartile range as appropriate. Correlations were tested with Spearman Rank-Order correlation.

Results

Baseline Characteristics
One-hundred fifty-one patients (age, 68.5 [60–78] years) were included (Table 1). The majority of patients had ischemic stroke (73.5%), 18.5% transient ischemic attack, and 8% cerebral hemorrhage. Median National Institutes of Health Stroke Scale score on admission was 3 (interquartile range, 1–9). Cardiac comorbidity was present in 65 (43%) patients (Table 1).

Automated Arrhythmia Detection
In total, 4809.5 monitoring hours were evaluated. A classification of alarms is given in Table 2. In total 22,509 alarms were detected. Overall, 72.6% and 73% nonlife threatening alarms were correct. Although National Institutes of Health Stroke Scale on admission was significantly correlated with the total number of alarms (r=0.26; 95% confidence interval, 0.1–0.4; P<0.01) and patients in the highest quartile of National Institutes of Health Stroke Scale had more alarms (P=0.023), the rate of false alarms did not differ between the 2 groups (P=0.33). In 31 patients (20.5%), acoustic alarms were transiently muted by medical personnel. Subgroup beat-to-beat analysis of complete ECG data revealed no missed events.

Life-Threatening Arrhythmia
Only 0.6% (n=140) of all alarms were allocated to life-threatening arrhythmias and 8.6% of these alarms were correct (Figure). The highest false alarm rate was observed for asystole with only 2 of 91 (2.2%) alarms corresponding to true asystole.

Discussion
Automated arrhythmia detection is part of Stroke Unit ECG monitoring to facilitate detection of arrhythmic complications but data on the validity of these systems are sparse. We show that the system is highly sensitive but also yields high rates of false alarms especially for life-threatening events. Several aspects emerge from the data.

Previous investigations on ICUs also revealed high overall number of alarms as well as high rates of false positive and clinically irrelevant findings. In contrast to our study, mostly sedated and ventilated patients were investigated. ECG monitoring of awake stroke patients implies special challenges with frequent bedside therapies (ie, physiotherapy) and patients who are restless and often aphasic, confused or disoriented because of their stroke symptoms. Nevertheless, the automated arrhythmia detection was highly sensitive. In addition, the overall rate of false alarms (27.4%) was in the range of previous findings (rates of 15–42%).

Nonlife-Threatening Events
In sharp contrast to their clinical relevance nonlife-threatening alarms produce the majority of acoustic alarms. Improvement of monitoring approaches including smarter detection algorithms is a target of intense research.8 Easy modifications such as individualization of alarm settings have been shown to reduce irrelevant alarms by ≤43%. Another approach is to limit acoustic alarms to life-threatening events and complement such monitoring with daily manual analyses of telemetric ECG data, which was shown to improve arrhythmia detection after stroke.11

Table 1. Baseline Characteristics

<table>
<thead>
<tr>
<th>Cohort characteristics</th>
<th>Age (median, IQR)</th>
<th>Sex (female)</th>
<th>TIA</th>
<th>Ischemic stroke</th>
<th>ICH/SAH</th>
<th>NIHSS on admission (median, IQR)</th>
<th>In-hospital mortality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (median, IQR)</td>
<td>68.5 (60–78)</td>
<td>66 (43.7%)</td>
<td>28 (18.5%)</td>
<td>111 (73.5%)</td>
<td>12 (8%)</td>
<td>3.0 (1.0–9.0)</td>
<td>7 (4.6%)</td>
</tr>
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Table 2. Classification of Alarms

<table>
<thead>
<tr>
<th>Monitoring hours</th>
<th>4809.5</th>
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</thead>
<tbody>
<tr>
<td>Number of alarms</td>
<td>22,509</td>
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<tr>
<td>Alarms per patient</td>
<td>149.1 ±344.4</td>
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<tr>
<td>Technically correct alarms</td>
<td>16,334 (72.6%)</td>
</tr>
<tr>
<td>Life-threatening alarms</td>
<td>140 (6.6%)</td>
</tr>
<tr>
<td>True positive life-threatening alarms</td>
<td>12/140 (8.6%)</td>
</tr>
<tr>
<td>False-negative alarms</td>
<td>0</td>
</tr>
<tr>
<td>Muting of alarms (n patients, %)</td>
<td>31 (20.5%)</td>
</tr>
</tbody>
</table>
Serious Arrhythmia

Compared to previously reported proportions of 20% for critical arrhythmias on pediatric ICUs\(^4\) and 12% on interdisciplinary ICUs, only 0.6% of alarms were in this group in our investigation. Differences in definitions and overall sicker patients on ICUs may account for that divergence. In concordance with our data showing only 8.6% true positive alarms in this subgroup, previous studies demonstrated high rates of false-positive alarms for serious arrhythmic events. For asystole, the most frequent malignant arrhythmia in our cohort, only 2.2% of alarms were correct. With serious arrhythmias being rare and particularly prone to false alarms, the probability for true positive alarms is low. As personnel matches their response with the expected probability of importance (human probability matching), this can lead to nonresponsiveness.\(^{13}\) Thus, despite the fact that no such critical incident was observed during our study, improvement of specificity in this group is of major importance.

Limitations

Limitations of this study are the single-center design with a limited number of patients. Nevertheless, it is the first prospective study focusing on the automated arrhythmia detection in the vulnerable ECG-monitoring phase after stroke.

Conclusions

Our results show that automated arrhythmia detection systems are sensitive in acute stroke. However, high rates of false alarms especially in serious arrhythmias may lead to noise disturbance, desensitization of staff, and even muting of acoustic alarms. Settings should be personalized and acoustic alarms
limited to events with direct clinical consequence. Manual analysis may complement automated systems.

Acknowledgments
This work was performed in fulfillment of the requirements for obtaining the degree Dr med.

Disclosures
Dr Schellinger is a member of the advisory board of Medtronic. The other authors report no conflicts.

References
Reliability and Limitations of Automated Arrhythmia Detection in Telemetric Monitoring After Stroke
Natalia Kurka, Tobias Bobinger, Bernd Kallmünzer, Julia Koehn, Peter D. Schellinger, Stefan Schwab and Martin Köhrmann

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