Reliability and Limitations of Automated Arrhythmia Detection in Telemetric Monitoring After Stroke

Natalia Kurka, MD*; Tobias Bobinger, MD*; Bernd Kallmünzer, MD; Julia Koehn, MD; Peter D. Schellinger, MD; Stefan Schwab, MD; Martin Köhrmann, MD

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

Guidelines recommend continuous ECG monitoring in patients admitted to a Stroke Unit. Previous reports on the effectiveness of such monitoring in intensive and intermediate care patients of several specialties1–3 demonstrate high sensitivity but low specificity.4,5 High rates of false-positive alarms leads to acoustic overload with noise levels ≤60 to 70 dB,5 desensitization of healthcare professionals and delayed or missing response to alarms, often called alarm fatigue or cry wolf phenomenon.1,6 Consequently, morbidity and mortality because of inadequate response and inappropriate deactivation of alarms were reported. Data on Stroke Unit patients is lacking. Although patients with stroke are at risk of serious cardiac arrhythmias, continuous ECG monitoring and detection of relevant events are important.7,8 At the same time, monitoring of patients with stroke can be demanding because they are awake, moving and often apathic, confused or disoriented because of their stroke symptoms. Current ECG-monitoring systems are vulnerable to misinterpretation of pseudoarrhythmias, movement and nursing-manipulation artifacts or even hiccups.9 We evaluated validity of standard automated arrhythmia detection in patients with stroke during Stroke Unit ECG monitoring.

Methods

Study Design

Consecutive patients with acute stroke admitted to our 14-bed Stroke Unit were prospectively included.

Continuous ECG Monitoring

Continuous 6-lead ECG monitoring was used as per clinical routine (Dräger, Infinity Series, Germany). The monitoring system includes standard automated arrhythmia detection with acoustic alarms. It distinguishes life-threatening arrhythmias with a specific sound indicating immediate required action. Other alarms are associated with a different acoustic signal. Life-threatening arrhythmias consist of asystole and ventricular arrhythmias (ventricular tachycardia, >120 bpm; ventricular fibrillation; and ventricular flutter). Nonlife-threatening events are supraventricular tachycardia (SVT) or sinustachycardia (>120 bpm) and bradycardia (<40 bpm), pause (>3 s), accelerated idioventricular rhythm, bigeminus, and couplet. Monitoring was set to the same initial settings and changes to settings or alarm thresholds were automatically recorded. Detected events were saved and
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 22509 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. 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.

Table 1. Baseline Characteristics

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

<table>
<thead>
<tr>
<th>Cardiac characteristics</th>
<th></th>
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<tbody>
<tr>
<td>Congestive heart failure</td>
<td>7</td>
<td>(4.6%)</td>
</tr>
<tr>
<td>Coronary heart disease</td>
<td>18</td>
<td>(11.9%)</td>
</tr>
<tr>
<td>History of stenting</td>
<td>8</td>
<td>(5.3%)</td>
</tr>
<tr>
<td>History of coronary artery bypass graft</td>
<td>6</td>
<td>(4.0%)</td>
</tr>
<tr>
<td>Pacemaker</td>
<td>5</td>
<td>(3.3%)</td>
</tr>
<tr>
<td>Atrial fibrillation</td>
<td>51</td>
<td>(33.8%)</td>
</tr>
<tr>
<td>Known before hospitalization</td>
<td>35</td>
<td>(23.2%)</td>
</tr>
<tr>
<td>Detection during ECG monitoring</td>
<td>10</td>
<td>(6.6%)</td>
</tr>
<tr>
<td>Detection during ECG monitoring</td>
<td>34</td>
<td>(22.5%)</td>
</tr>
</tbody>
</table>

| STEMI during hospitalization | 2 | (1.3%) |
| NSTEMI during hospitalization | 6 | (4%) |
| Antiarrhythmic therapy      | 74 | (49%) |
| β-blocker therapy           | 68 | (45%) |
| Digitalis therapy           | 16 | (10.6%) |
| Ca-channel blocker therapy  | 10 | (6.6%) |

| AF indicates atrial fibrillation; ICH, intracerebral hemorrhage; IQR, interquartile range; NIHSS, National Institutes of Health Stroke Scale; NSTEMI, non–ST-segment–elevation myocardial infarction; SAH, subarachnoid hemorrhage; STEMI, ST-segment–elevation myocardial infarction; TIA, transient ischemic attack; and Trop I, Troponin I. |
Serious Arrhythmia

Compared to previously reported proportions of 20% for critical arrhythmias on pediatric ICUs\(^1\) and 12% on interdisciplinary ICUs,\(^4\) 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

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**Figure.** Analysis for arrhythmia identification for (A) nonlife-threatening and (B) life-threatening arrhythmias. AIVR indicates accelerated idioventricular rhythm; ASY, asystole; BGM, bigeminus; CPT, couplet; SVT, supraventricular tachycardia; VF, ventricular flutter; and VT, ventricular tachycardia.
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
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