

# The additional value of an algorithm for atrial fibrillation at the stroke unit

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*Background and purpose:* The rate of newly detected (paroxysmal) atrial fibrillation (AF) during inpatient cardiac telemetry is low. The objective of this study was to evaluate the additional diagnostic yield of an automated detection algorithm for AF on telemetric monitoring compared with routine detection by a stroke unit team in patients with recent ischemic stroke or TIA. *Methods:* Patients admitted to the stroke unit of Medisch Spectrum Twente with acute ischemic stroke or TIA and no history of AF were prospectively included. All patients had telemetry monitoring, routinely assessed by the stroke unit team. The ST segment and arrhythmia monitoring (ST/AR) algorithm was active, with deactivated AF alarms. After 24 h the detections were analyzed and compared with routine evaluation. *Results:* Five hundred and seven patients were included (52.5% male, mean age 70.2 ± 12.9 years). Median monitor duration was 24 (interquartile range 22–27) h. In 6 patients (1.2%) routine analysis by the stroke unit team concluded AF. In 24 patients (4.7%), the ST/AR Algorithm suggested AF. Interrater reliability was low ( $\kappa$ , 0.388,  $p < 0.001$ ). Suggested AF by the algorithm turned out to be false positive in 11 patients. In 13 patients (2.6%) AF was correctly diagnosed by the algorithm. None of the cases detected by routine analysis were missed by the algorithm. *Conclusions:* Automated AF detection during 24-h telemetry in ischemic stroke patients is of additional value to detect paroxysmal AF compared with routine analysis by the stroke unit team alone. Automated detections need to be carefully evaluated.

**Keywords:** Algorithms—Atrial fibrillation—Brain Ischemia—Telemetry—Ischemic attack—Transient

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## Introduction

Atrial fibrillation (AF) increases the risk of stroke 5-fold.<sup>1–6</sup> Treatment with vitamin K antagonists or novel oral anticoagulants is very effective to prevent recurrent

ischemic stroke in patients with AF, with a risk reduction of approximately 60%.<sup>1,3,4,7</sup>

The 2018 AHA/ASA stroke guideline recommends heart rhythm monitoring for at least 24 h after stroke.<sup>3</sup> The Dutch guideline recommends to extend the

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monitoring period with 72 h in patients with ischemic stroke of undetermined cause.<sup>8</sup>

AF detection rates are low since AF is often transient and frequently asymptomatic.<sup>1,2</sup> A meta-analysis showed a rate of newly detected AF in 4.1% of 2783 patients during continuous inpatient cardiac telemetry.<sup>9</sup> The low detection rate might be due to missed AF episodes by insufficient trained staff, unattended time periods or the absence of automated detection algorithms. Several studies have evaluated different strategies for in-hospital heart rhythm monitoring with contradicting results.<sup>10–13</sup> However, no specific real-time monitor-algorithm for the detection of AF was used. One of the existing monitoring algorithms is the ST segment and arrhythmia monitoring (ST/AR) algorithm used on Philips ECG monitors. The AF episode detection of this algorithm has been shown to have a sensitivity of 95%.<sup>14</sup>

## Aims

The objective of this study was to evaluate the additional diagnostic yield of a real-time automated detection algorithm for AF on in-hospital cardiac telemetric monitoring compared to routine detection by a stroke unit team in patients with recent ischemic stroke.

## Methods

### *Study design*

Consecutive patients with ischemic stroke or TIA who were admitted to the stroke unit of Medisch Spectrum Twente, a large teaching hospital in the Netherlands, were prospectively included between May 2015 and June 2016. Stroke mimics and patients with a history of AF or AF on admission ECG were excluded. Data on patient characteristics, type of ischemic event, vascular history and risk factors were recorded. All patients had ECG on admission, routine laboratory assessments, brain CT and imaging of the carotid arteries (by Doppler ultrasonography, CT-angiography or MR-angiography). Stroke severity was assessed with the NIH Stroke Scale and the cause of stroke was classified according to the Trial of ORG 10172 in Acute Stroke (TOAST) classification.<sup>15</sup> Ischemic stroke and TIA were subdivided in cortical, subcortical, lacunar and borderzone stroke based on clinical and imaging findings. The local Medical Ethical Committee stated that the study did not meet the criteria necessary for an assessment by a medical ethical committee according to Dutch law.

### *Heart rhythm monitoring*

The heart rhythm of all patients was continuously recorded with the Philips IntelliVue MX-450 monitor using a 5-lead ECG registration. Registrations were visible on a screen next to the patient and a second screen in the central stroke unit station. The ST segment and

arrhythmia monitoring (ST/AR) algorithm was active. The AF alarm was visually and auditory deactivated for the stroke unit staff. All other alarms, including high priority alarms, were activated and stroke unit staff was able to react on them immediately. The rhythm was not monitored continuously by the stroke unit team, but reviewed at random intervals, when a patient had cardiac symptoms or when an alarm (other than AF) went off. The stroke unit team consisted of stroke nurses, a neurology resident and a stroke neurologist. When a member of the stroke unit team suspected AF from the monitoring data, a 12-lead ECG was made and reviewed by a trained physician. After 24 h of monitoring, the monitoring period recommended by guidelines, the recorded rhythm and detected arrhythmias were independently analyzed by trained Neurology residents (GP, ID, SS or TL), blinded for the AF detection outcomes of the stroke unit team. In case of uncertainty, the record was also reviewed by a cardiologist.

### *Definitions and algorithm features*

AF was defined as a sequence of at least 30 s irregular R-R intervals in the absence of distinct P waves.<sup>1,16</sup> The ST/AR Algorithm uses three features for AF detection: R-R irregularity, PR interval variability and P-wave variability. For AF to be detected, the normal beat R-R intervals must be irregular, the PR interval deviation must be large and the P-wave region must not match well, all for a minimum period of 15 s. An AF detection occurs when these criteria are met for four consecutive 15-s intervals. AF lasting between 30 and 60 s will not be detected by the algorithm. Atrial flutters cannot be detected by the algorithm because their regular R-R intervals.

### *Statistics*

All statistics were performed using SPSS 22.00 (Statistical Package for the Social Sciences, Version 22.0, SPSS, Chicago, IL). Patient characteristics are displayed as number (%) for categorical variables and as mean with standard deviation (SD) or median with interquartile range (IQR) for continuous variables. Differences between patients without AF and patients with AF de novo were tested with an independent *T*-test or Mann–Whitney *U*-test, and for categorical variables a Chi-square test or Fisher exact test was used as appropriate. Interrater reliability between the two detection methods was determined using  $\kappa$ -statistics. A significance level of 0.05 was used.

## Results

Between May 2015 and June 2016, 803 patients were admitted to the stroke unit with a presumed diagnosis of ischemic stroke or TIA. Seventy-five of them (7.1%) were finally diagnosed as a stroke mimic. Of the 728 patients

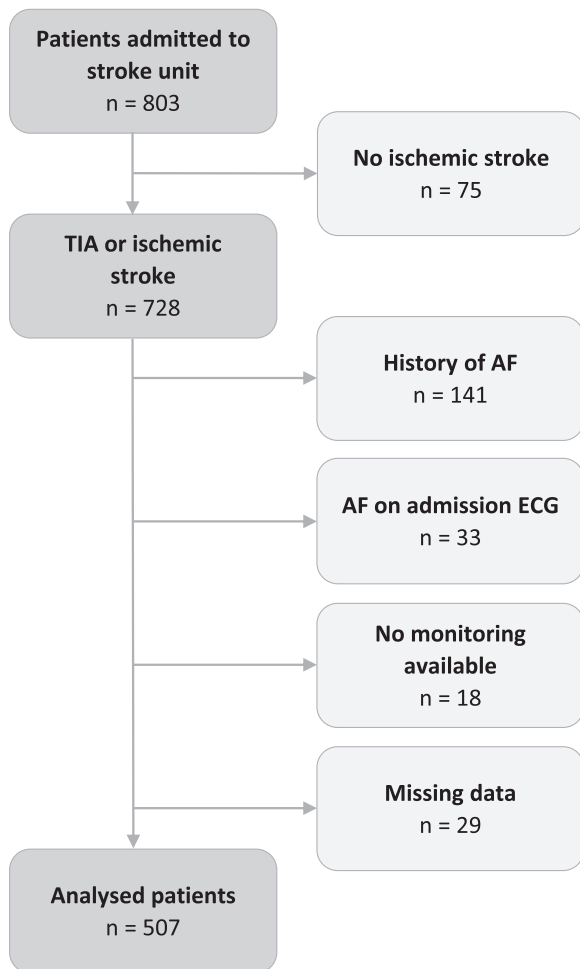


Fig. 1. Flowchart of patient inclusion.

diagnosed with ischemic stroke or TIA, 141 patients had a history of AF (19.4%), and 33 patients were newly diagnosed with AF based on admission ECG (4.5%). Therefore, 554 patients were eligible for the study. Because of a lack in available monitors, 18 patients did not receive telemetry monitoring, and from 29 patients monitoring data were not complete. This left 507 patients for analysis (Fig. 1).

Patient and event characteristics are shown in Table 1. Of the total study population 52.5% was male, mean age was 70.2 ( $\pm$  12.9) years and median monitor duration was 24 (IQR 22–27) h. Patients with newly diagnosed AF during monitoring were older ( $p=0.021$ ) and had more severe strokes ( $p=0.001$ ).

In 6 patients (1.2%) analysis by the stroke unit team concluded newly diagnosed AF. In 24 patients (4.7%), the ST/AR Algorithm suggested AF. Calculation of the interrater reliability concluded a slight agreement between the two detection methods ( $\kappa=0.388$ ,  $p < 0.001$ ). Details are shown in Table 2.

After evaluation of the AF detections of the ST/AR Algorithm presumed AF turned out to be a false positive in 11 patients. Thirteen patients were correctly diagnosed

with new AF by the algorithm, which is 2.6% of the total patient population. All 6 patients found by the stroke unit team evaluation were correctly diagnosed, and also recognized by the algorithm. The sensitivity, specificity, positive predictive values and negative predictive values of both methods are listed in Table 3. Characteristics of the incorrect AF detections by the algorithm are shown in Table 4.

## Discussion

We found that the use of a telemetry algorithm for detection of AF led to a more than 2-fold increase of detection rate compared with routine stroke unit team evaluation. Our detection rate is lower than the 4.1% Sposato et al. found.<sup>9</sup> This difference could be explained by their significantly longer mean monitoring period (4.3 days versus 24 h in our study).

Kurka et al. found a high sensitivity of continuous ECG monitoring using automated arrhythmia detection in 151 patients with acute stroke and high rates of false alarms, but their focus was not to detect AF and a specific AF alarm was not present.<sup>17</sup>

Several other studies compared different heart rhythm monitoring strategies targeting AF detection in stroke patients.

One study by Rizos et al. analyzed continuous bedside ECG monitoring with alarming for arrhythmias, without automatic AF detection, in 136 patients with acute ischemic stroke or TIA over 60 years old and no history of AF.<sup>10</sup> 24-h Holter monitoring was added unless patients had already showed AF. Continuous bedside monitoring (mean duration 97 h) detected AF in 29 patients (21.3%). In 16 of these patients, AF was detected before adding Holter monitoring. In the remaining 120 patients who underwent both monitoring methods, Holter ECG detected AF in 3 patients and patient bedside monitoring in 13 patients.

Another study by Lazarro et al. compared concurrent Holter monitoring and continuous telemetry in 133 patients with acute stroke or TIA and no history of AF.<sup>11</sup> A cardiologist interpreted each Holter study, and telemetry was reviewed by nursing staff every 8 h or in case of an arrhythmia alarm. A specific AF alarm was not present. Holter monitoring (mean 29.8 h) provided a significantly higher rate of AF detection compared with continuous cardiac telemetry (mean 73.4 h), with 8 (6.0%) and 0 detected cases, respectively.

A study by Kallmünzer et al. of 245 ischemic stroke patients with no history of AF compared serial ECG assessments, standard telemetric monitoring and a structured evaluation algorithm for AF (SEA-AF).<sup>12</sup> Automatic arrhythmia detection in standard telemetric monitoring did not recognize AF. In SEA-AF the full registrations were daily reviewed. Serial ECG's and standard telemetric monitoring detected 8 (3.3%) and 7 (2.9%) cases of AF

**Table 1.** Characteristics of included patients.

Baseline characteristics	Total <i>n</i> = 507	No AF <i>n</i> = 494	AF de novo <i>n</i> = 13	<i>p</i> value
Male	266 (52.5)	260 (52.6)	6 (46.2)	0.644
Age (years)	70.2 (± 12.9)	70.0 (± 12.9)	78.3 (± 9.5)	0.021
<i>Cardiovascular risk factors</i>				
Hypertension	343 (67.7)	334 (67.6)	9 (69.2)	1.000
Diabetes	118 (23.3)	115 (23.3)	3 (23.1)	1.000
Dyslipidaemia	425 (83.8)	416 (84.2)	9 (69.2)	0.119
Smoking	121 (23.9)	121 (24.5)	0 (0)	0.045
<i>History of</i>				
TIA	64 (12.6)	63 (12.8)	1 (7.7)	1.000
Ischemic stroke	87 (17.2)	84 (17.0)	3 (23.1)	0.476
Myocardial infarction	72 (14.2)	71 (14.4)	1 (7.7)	1.000
Peripheral vascular disease	26 (5.1)	26 (5.3)	0 (0)	1.000
<i>Type of event</i>				
TIA	111 (21.9)	109 (22.1)	2 (15.4)	0.743
Ischemic stroke	396 (78.1)	385 (77.9)	11 (84.6)	
NIHSS	2 (1-5)	2 (1-5)	9 (3-15)	0.001
<i>Localization</i>				
Cortical	234 (46.2)	224 (45.3)	10 (76.9)	
Subcortical	120 (23.7)	117 (23.7)	3 (23.1)	
Lacunar	151 (29.8)	151 (30.6)	0 (0)	
Borderzone	2 (0.4)	2 (0.4)	0 (0)	
Duration of monitoring (h)	24 (22-27)	24 (22-27)	24.5 (21.3-41.3)	0.569

Data are presented as *n* (%) except for age [mean (±SD)], NIHSS (National Institute of Health Stroke Scale) [median (Inter Quartile Range)] and duration of monitoring [median (Inter Quartile Range)].

respectively, whereas SEA-AF identified 18 cases (7.3%). The median telemetric monitoring time was 75.5 h.

**Table 2.** Agreement of AF detection by the stroke unit team and ST/AR algorithm.

		ST/AR Algorithm	
		No AF	AF
Stroke unit team	No AF	483	18
	AF	0	6

$\kappa = 0.388$ ;  $p < 0.001$  (95% CI 0.169-0.608).

Uphaus et al. compared the diagnostic effectiveness of routine staff-based analysis (RA) and use of a software algorithm (SA) for analyzing in-hospital Holter monitoring (mean 28.5 h) in 580 patients with ischemic stroke.<sup>13</sup> The RA used software to identify episodes of suspected arrhythmia, and a senior cardiologist performed a rating of the ECG data with regard to the occurrence of AF. Nineteen patients (3.3%) had AF, no significant difference between the two strategies were found.

Reasons for the differences in AF detection between these studies could be variations in monitoring times, since longer monitoring duration leads to a higher detection rate of AF<sup>18,19</sup> and different patient selections. Rizos et al. only included patients older than 60, who have a

**Table 3.** AF detection by the stroke unit team and ST/AR algorithm after correction and performance measures of both strategies

AF	Stroke unit team	95% CI	Algorithm	95% CI
Detected	6 (1.2)		24 (4.7)	
Correctly detected	6 (1.2)		13 (2.6)	
False positive	0		11 (2.2)	
False negative	7 (1.4)		—*	
Sensitivity	46.2	20.4–73.9	100	71.2–100
Specificity	100	99.0–100.0	97.8	95.9–98.8
PPV	100	51.6–100.0	54.2	33.2–73.7
NPV	98.6	97.0–99.4	100	99.0–100

Data are presented as *n* (%). Values for sensitivity, specificity, PPV (positive predictive value) and NPV (negative predictive value) are presented as percentages. \*No AF alarms detected by the stroke unit were missed by the algorithm. It is unknown if an AF period was missed by both methods.

**Table 4.** Characteristics of ECG monitoring data with falsely detected AF by the algorithm.

No.	Monitoring duration (h)	AF alarms (n)	Interpretation of ECG data by a physician
1.	28	97	Atrial tachycardias
2.	27	17	Baseline irregularity
3.	23	41	First degree AV block
4.	20	3	P-wave not recognized due to low amplitude
5.	21	8	P-wave not recognized due to low amplitude
6.	23	7	Sinus arrhythmia and baseline irregularity
7.	37	5	Sinus arrhythmia and low P-wave amplitude
8.	19	8	Sinus arrhythmia and PACs
9.	24	5	Sinus arrhythmia and PACs
10.	26	70	Sinus arrhythmia and PACs
11.	25	1	Third degree AV block

AV block = atrioventricular block, PACs = premature atrial contractions.

higher chance of AF.<sup>20</sup> Kallmünzer et al. did not include patients with TIA or a symptom duration of more than 3 days, making the diagnosis of cerebral ischemia more certain and making sure rhythm analysis was performed shortly after the ischemic event. Differences could also be explained by the single-center design. Evaluation methods of telemetric monitoring, ECG-reading abilities of stroke unit staff and available reviewing time probably vary between hospitals. Also, staff could be more alert of possible rhythm abnormalities when they are aware that this is being investigated.

Our findings showed only a slight interrater agreement between stroke unit team analysis and the ST/AR algorithm because the algorithm detected four times as many AF. However, careful evaluation showed that 11 out of 24 patients (45.8%) were falsely diagnosed with AF by the algorithm. This demonstrates that all AF alarms need to be thoroughly assessed. Misinterpretation of the algorithm was caused by ECG characteristics or artifacts mimicking AF. Several ECG segments of patients with atrial tachycardias, atrioventricular block or sinus arrhythmia with premature atrial contractions were wrongfully marked as AF. Also, technical aspects such as failure to recognize P-waves due to low amplitudes and baseline irregularity contributed to incorrect AF detections.

The SA strategy Uphaus et al. used had a lower false-positive rate of 4 out of 21 AF detections, probably due to differences in technical properties of the software. Also, ECG data was analyzed afterwards in contrast to the real-time analysis of the ST/AR algorithm.

Kallmünzer et al.<sup>12</sup> showed a more than 2-fold increase of AF detections when comparing a structured review of the ECG data with standard monitoring. This is however a time consuming and expensive method. Since our study showed an almost similar increase of detected AF when adding an automatic AF detection algorithm to standard monitoring evaluation, this could be a time efficient and cost-effective alternative to detect paroxysmal AF at the stroke unit.

### Limitations

Our study has some limitations. First, we did not perform an evaluation of the complete ECG data to assess if AF was missed by the algorithm. This could have led to an overestimation of the sensitivity of the algorithm. Due to limited storage possibilities, the complete ECG monitoring data at the stroke unit were only available for assessment for a short time period. All relevant data (types and amount of alarms and evaluation of them) were extracted from the monitoring results and stored in a database, but these data do not include all 24-h of rhythm strips. A performance assessment of the ST/AR algorithm by Philips Medical Systems using 234 patient-records showed a sensitivity of 95% for AF episode detection.<sup>14</sup> Second, episodes of atrial flutter and AF lasting less than 1 min were not recognized by the algorithm. At present, it is unknown what the minimum AF duration is to have a causal relationship with ischemic stroke. There is growing evidence suggesting the risk of stroke increases with longer AF duration.<sup>21–25</sup> A benefit of oral anticoagulation in patients with AF duration less than one to several minutes, has not been shown yet. Third, we found a high number of false positive alarms. To prevent an incorrect diagnosis and subsequent therapy changes a careful evaluation of all the alarms is necessary. Finally, the diagnostic yield of 2.6% is low compared to other studies but could be explained by the relative short monitoring period. A 24-h period was chosen based on guidelines and practical reasons, since the stroke unit is a department with a high flow of patients demanding telemetry monitoring.

### Conclusions

In summary, our results suggest that automatic AF detection during 24-h telemetry in ischemic stroke patients is of additional value to detect AF de novo compared to routine analysis by the stroke unit team alone. The presence of false positive alarms asks for a careful evaluation of the findings.

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