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CLINICAL RESEARCH

Performance of a multi-sensor implantable defibrillator algorithm for heart failure monitoring in the presence of atrial fibrillation

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Aims The HeartLogic Index combines data from multiple implantable cardioverter defibrillators (ICDs) sensors and has been shown to accurately stratify patients at risk of heart failure (HF) events. We evaluated and compared the performance of this algorithm during sinus rhythm and during long-lasting atrial fibrillation (AF).

Methods and results HeartLogic was activated in 568 ICD patients from 26 centres. We found periods of ≥30 consecutive days with an atrial high-rate episode (AHRE) burden <1 h/day and periods with an AHRE burden ≥20 h/day. We then identified patients who met both criteria during the follow-up (AHRE group, $n = 53$), to allow pairwise comparison of periods. For control purposes, we identified patients with an AHRE burden <1 h throughout their follow-up and implemented 2:1 propensity score matching vs. the AHRE group (matched non-AHRE group, $n = 106$). In the AHRE group, the rate of alerts was 1.2 [95% confidence interval (CI): 1.0–1.5]/patient-year during periods with an AHRE burden <1 h/day and 2.0 (95% CI: 1.5–2.6)/patient-year during periods with an AHRE-burden ≥20 h/day ($P = 0.004$). The rate of HF hospitalizations was 0.34 (95% CI: 0.15–0.69)/patient-year during IN-alert periods and 0.06 (95% CI: 0.02–0.14)/patient-year during OUT-of-alert periods ($P < 0.001$). The IN/OUT-of-alert state incidence rate ratio of HF hospitalizations was 8.59 (95% CI: 1.67–55.31) during periods with an AHRE burden <1 h/day and 2.70 (95% CI: 1.01–28.33) during periods with an AHRE burden ≥20 h/day. In the matched non-AHRE group, the rate of HF hospitalizations was 0.29 (95% CI: 0.12–0.60)/patient-year during IN-alert periods and 0.04 (95% CI: 0.02–0.08)/patient-year during OUT-of-alert periods ($P < 0.001$). The incidence rate ratio was 7.11 (95% CI: 2.19–22.44).

Conclusion Patients received more alerts during periods of AF. The ability of the algorithm to identify increased risk of HF events was confirmed during AF, despite a lower IN/OUT-of-alert incidence rate ratio in comparison with non-AF periods and non-AF patients.

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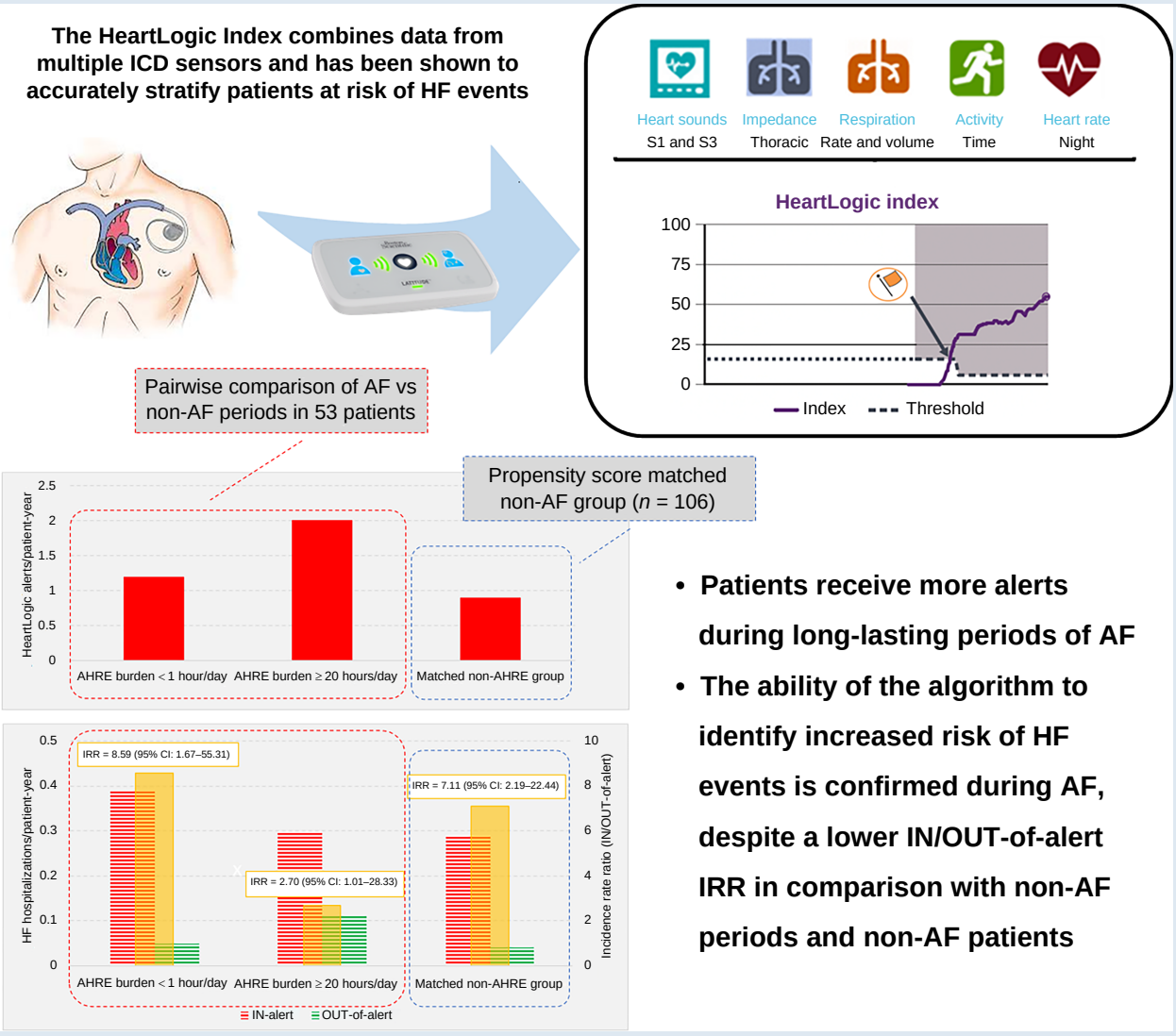
Graphical Abstract



Keywords Heart failure • ICD • CRT • Atrial fibrillation • Risk stratification

What's new?

- During periods of long-lasting atrial fibrillation (AF), patients receive more HeartLogic alerts.
- The ability of the algorithm to identify increased risk of heart failure (HF) events is confirmed during AF.
- However, the IN/OUT-of-alert incidence rate ratio of HF events is lower during long-lasting atrial arrhythmia episodes.

Introduction

Some modern implantable cardioverter defibrillators (ICDs) and defibrillators for resynchronization therapy [cardiac resynchronization therapy defibrillators (CRT-Ds)] are equipped with automated algorithms that provide detailed information on the heart failure (HF) condition on a daily basis.[1] Because of the inconsistent results of studies that investigated the ability of single-sensor ICD diagnostics to identify patients at risk of HF events,[2–7] diagnostic algorithms have been developed to combine data from multiple sensors, in order to better stratify and manage patients at

risk of HF events.[8–12] In the Multisensor Chronic Evaluation in Ambulatory Heart Failure Patients (MultiSENSE) study,[9] a multi-sensor algorithm for HF monitoring was implemented: the HeartLogic (Boston Scientific, St. Paul, MN, USA) Index, which combines multiple ICD-based sensors in order to identify periods when patients are at significantly increased risk of worsening HF.[13] However, there are no data on its performance in the presence of atrial arrhythmias, which are common in HF patients and are known to affect disease severity and prognosis.[14–16] Indeed, the different triggering mechanisms of worsening HF episodes during atrial fibrillation (AF), e.g. loss of biventricular pacing or uncontrolled ventricular rate,[17–19] might result in a different performance of the diagnostic algorithm. Moreover, a different performance of the diagnostic algorithm cannot be excluded in patients with AF, since ventricular rate is one of the contributing parameters of the combined index, and an irregular heart rate could impact the accelerometer-based assessment of first and third heart sounds.

In the present study, we sought to evaluate and compare the performance of the HeartLogic algorithm during sinus rhythm and during long-lasting AF episodes.

Methods

Patient selection

The study was a retrospective analysis of data from patients who had received an ICD or CRT-D endowed with the HeartLogic™ diagnostic algorithm. Consecutive HF patients with reduced left ventricular ejection fraction (≤35% at the time of implantation) who had received a device in accordance with the standard indications[20] and were enrolled in the LATITUDE (Boston Scientific) remote monitoring platform were included at 26 study centres (full list of participating centres in Supplementary material online) and followed up in accordance with the standard practice of the participating centres. Clinicians periodically checked the remote monitoring website for transmissions. Moreover, remote data reviews and patient phone contacts were undertaken at the time of HeartLogic alerts, to assess the patient's decompensation status and, if possible, to prevent further worsening. However, the study protocol did not mandate any specific intervention algorithm, and physicians were free to remotely implement clinical actions or to schedule extra in-office visits when deemed necessary. Data on the clinical events that occurred during follow-up were collected at the study centres within the framework of a prospective registry (ClinicalTrials.gov identifier: NCT02275637). The institutional review boards approved the study, and all patients provided written informed consent for data storage and analysis.

Device characteristics

Commercially available ICD/CRT-Ds equipped with the HeartLogic™ diagnostic feature and standard transvenous leads were used in this study. The details of the HeartLogic algorithm have been reported previously.[9] Briefly, the algorithm combines data from multiple sensors: accelerometer-based first and third heart sounds, intra-thoracic impedance, respiration rate, the ratio of respiration rate to tidal volume, night heart rate, and patient activity. Each day, the device calculates the degree of worsening in sensors from their moving baseline and computes a composite index. An alert is issued when the index crosses a programmable threshold (nominal value: 16). When the index enters an alert state, the 'exit-alert' threshold is automatically dropped to a recovery value (nominal value: 6).

Analysis design

The objective of the present analysis was to compare the performance of the HeartLogic algorithm during consistent sinus rhythm and during long-lasting atrial arrhythmia episodes.

We therefore analysed device-stored data to identify periods of at least 30 consecutive days with an atrial high-rate episode (AHRE) burden <1 h/day and periods of at least 30 consecutive days with an AHRE burden of 20 h/day or more. We then identified patients who met both criteria during their follow-up (AHRE group), in order to allow pairwise comparisons between AHRE burden <1 h/day and AHRE burden ≥20 h/day. We compared the rate of HeartLogic alerts, the proportion of time IN-alert, the rate of HF hospitalizations, the incidence rate ratio (IRR) of HF hospitalizations between IN-alert and OUT-of-alert periods, and the average values of the HeartLogic index and its contributing sensors. Additionally, we also compared the false-positive rate, computed as the ratio of the number of false-positive alerts (i.e. the alert onset occurred and reset before an endpoint) over the duration of periods with AHRE burden <1 h/day and ≥20 h/day. For control purposes, we identified a group of patients with AHRE burden <1 h/day during the entire follow-up (unmatched non-AHRE group). We then implemented propensity score matching vs. the AHRE group, to identify the matched non-AHRE group.

Statistical analysis

Quantitative variables are reported as means ± SD if normally distributed or medians with 25–75th percentiles in the case of skewed distribution. Normality of distribution was tested by means of the non-parametric Kolmogorov–Smirnov test. Categorical data are expressed as percentages. Differences between mean data were compared by means of a *t*-test for Gaussian variables and Mann–Whitney or Wilcoxon non-parametric test for non-Gaussian variables for independent or paired samples, respectively. Differences in proportions were compared by means of χ^2 analysis. Clinical event rates were calculated separately during IN and OUT alert states in terms of the ratio between the total count of events occurring in each state and the respective duration of patient follow-up and were expressed as events per patient-year. We implemented 2:1 nearest-neighbour propensity score matching without replacement, the propensity score being estimated by means of logistic regression of the effect of treatment on the covariates. The variables used to calculate the propensity score are shown in *Table 1*. After matching, all standardized mean differences among the covariates were below 0.1, indicating adequate balance. Cox proportional hazards model was used to determine the association between patients' characteristics and the occurrence of events during the follow-up period and to estimate the hazard ratio (HR) and the 95% confidence interval (CI) of an episode. The average daily values of the HeartLogic index and its sensors were recorded over the months before and after the occurrence of an alert, and the time course of changes surrounding the alert was plotted.

In patients with AHRE episodes, averaged sensor data were calculated during periods with an AHRE burden ≥20 h/day and an AHRE burden <1 h/day and in patients of the matched non-AF group during the overall follow-up. A *P*-value <0.05 was considered significant for all tests. All statistical analyses were performed by means of R: a language and environment for statistical computing (R Foundation for Statistical Computing, Vienna, Austria).

Results

Study population

From December 2017 to June 2021, HeartLogic was activated in 568 patients who had received an ICD ($n = 158$) or CRT-D ($n = 410$). The index threshold was programmed to the nominal value of 16 in all patients and was not modified during follow-up. *Table 1* shows the baseline clinical variables of all patients in the present analysis.

Follow-up and study groups

The median follow-up was 26 months (25–75th percentile: 16–37). During the observation period, 53 hospitalizations for cardiovascular reasons were reported, and 55 patients died. The HeartLogic index crossed the threshold value 1200 times (0.71 alerts/patient-year) in 370 patients. The cumulative distribution of daily AHRE burden during the observation period is shown in *Figure 1*. An AHRE burden of ≥1 h/day was documented in 154 (27%) patients and of ≥20 h/day in 95 (17%) patients. Among the latter, we identified 53 patients (AHRE group) who experienced an AHRE burden ≥20 h/day for at least 30 consecutive days in addition to an AHRE burden <1 h/day for ≥30 consecutive days. The remaining 414 patients with an AHRE burden <1 h/day during the entire follow-up constituted the unmatched non-AHRE group. *Table 1* shows the comparison between the AHRE

Table 1 Demographics and baseline clinical parameters of the study population and the unmatched and propensity score-matched cohorts

Parameter	Total (568)	AHRE group (53)	Unmatched non-AHRE group (414)	Matched non-AHRE group (106)
Male gender[a], *n* (%)	453 (80)	47 (89)	328 (79)	100 (94)
Age[a], years	69 ± 10	72 ± 10	69 ± 10[b]	72 ± 8
Ischaemic aetiology, *n* (%)	285 (50)	26 (49)	201 (49)	56 (53)
NYHA class				
Class I, *n* (%)	36 (6)	5 (9)	27 (6)	4 (4)
Class II, *n* (%)	351 (62)	28 (53)	261 (63)	73 (69)
Class III, *n* (%)	171 (30)	19 (36)	119 (29)	29 (27)
Class IV, *n* (%)	10 (2)	1 (2)	7 (2)	0 (0)
LV ejection fraction[a], %	32 ± 9	32 ± 9	32 ± 9	31 ± 8
AF history, *n* (%)	196 (35)	41 (77)	115 (28)[b]	44 (42)[b]
AF on implantation, *n* (%)	100 (18)	23 (43)	70 (17)[b]	24 (23)[b]
Diabetes, *n* (%)	167 (29)	19 (36)	124 (30)	37 (35)
COPD, *n* (%)	89 (16)	15 (28)	57 (14)[b]	17 (16)
Chronic kidney disease[a], *n* (%)	153 (27)	24 (45)	99 (24)[b]	43 (41)
Hypertension, *n* (%)	334 (59)	33 (62)	246 (59)	74 (70)
β-Blocker use, *n* (%)	520 (92)	46 (87)	383 (93)	94 (89)
ACE-I, ARB, or ARNI use, *n* (%)	536 (94)	51 (96)	390 (94)	104 (98)
Diuretic use, *n* (%)	506 (89)	46 (87)	364 (88)	97 (92)
Antiarrhythmic use, *n* (%)	116 (20)	16 (30)	73 (18)[b]	21 (20)
CRT device[a], *n* (%)	410 (72)	45 (85)	291 (70) [b]	91 (86)
Primary prevention, *n* (%)	500 (88)	45 (85)	363 (88)	94 (89)

AHRE, atrial high-rate episode; NYHA, New York Heat Association; LV, left ventricular; AF, atrial fibrillation; COPD, chronic obstructive pulmonary disease; ACE-I, angiotensin-converting-enzyme inhibitor; ARB, angiotensin II receptor blocker; ARNI, angiotensin receptor-neprilysin inhibitor; CRT, cardiac resynchronization therapy.
[a]Variables were used for the calculation of propensity scores.
[b]$P < 0.05$ vs. AHRE group.

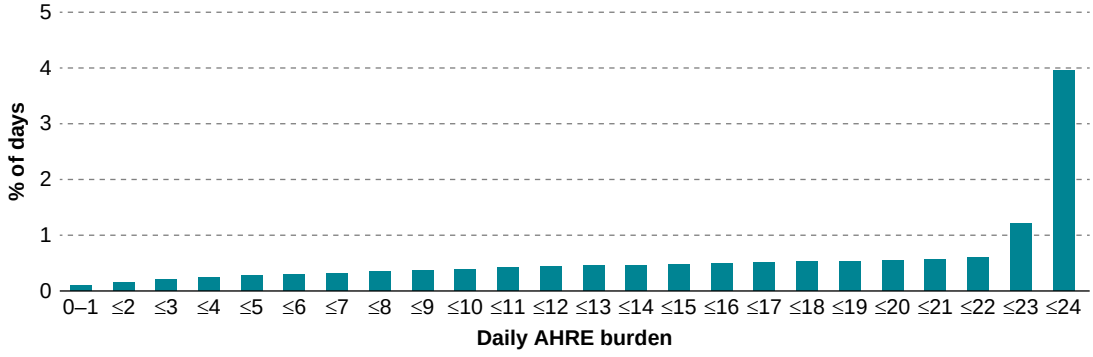


Figure 1 Cumulative distribution of daily atrial high-rate episode (AHRE) burden during the observation period in the overall population ($n = 568$).

and unmatched non-AHRE groups. Patients in the AHRE group were older, more frequently had a history of AF, had AF on implantation, had chronic obstructive pulmonary disease and had kidney diseases and were more often on antiarrhythmics and CRT. Propensity score matching identified 106 patients who constituted the matched non-AHRE group. The baseline clinical variables of the AHRE group and the matched non-AHRE group were comparable, except for 'history of AF' and 'AF on implantation' (*Table 1*).

HeartLogic alerts

In the AHRE group, the median duration of periods with an AHRE burden <1 h/day was 134 days (25–75th percentile: 62–342), while the duration of periods with an AHRE burden ≥20 h/day was 95 days (25–75th percentile: 53–175). The rate of HeartLogic alerts was 1.2 (95% CI: 1.0–1.5)/patient-year during periods with an AHRE burden <1 h/day and 2.0 (95% CI: 1.5–2.6)/patient-year during periods with an AHRE burden ≥20 h/day ($P = 0.004$). The proportion of time in alert

was 16% vs. 35% ($P < 0.001$). The rate of HF hospitalizations was 0.10 (95% CI: 0.04–0.20)/patient-year during periods with an AHRE burden <1 h/day and 0.18 (95% CI: 0.06–0.42)/patient-year during periods with an AHRE burden ≥20 h/day ($P = 0.302$). On stratifying the periods according to the HeartLogic alert status, the rate of HF hospitalizations was 0.34 (95% CI: 0.15–0.69)/patient-year during IN-alert periods and 0.06 (95% CI: 0.02–0.14)/patient-year during OUT-of-alert periods ($P < 0.001$). Comparisons of the event rates in the IN-alert state with those in the OUT-of-alert state yielded an IRR of 8.59 (95% CI: 1.67–55.31) for HF hospitalizations during periods with an AHRE burden <1 h/day and 2.70 (95% CI: 1.01–28.33) during periods with an AHRE burden ≥20 h/day.

The median follow-up of the matched non-AHRE group was 26 months (25–75th percentile: 14–37). During the observation period, the HeartLogic index crossed the threshold value 206 times, i.e. 0.94 (95% CI: 0.82–1.08) alerts/patient-year ($P < 0.05$ vs. periods with AHRE burden <1 h/day and ≥20 h/day in the AHRE group). The proportion of time in alert was 11% ($P < 0.05$ vs. both periods in the AHRE group). The rate of HF hospitalizations was 0.07 (95% CI: 0.04–0.11)/patient-year. This rate was 0.29 (95% CI: 0.12–0.60)/patient-year during IN-alert periods and 0.04 (95% CI: 0.02–0.08)/patient-year during OUT-of-alert periods ($P < 0.001$). The IRR was 7.11 (95% CI: 2.19–22.44). On multivariate regression analysis, significant associations with HF hospitalizations were found for the time in alert state (HR: 11.1, 95% CI: 1.28–95.9, $P < 0.001$) and presence of AHRE (HR: 2.42, 95% CI: 1.09–5.41, $P = 0.032$), after correction for baseline confounders, including AF on implantation and history of AF. In patients with AHRE, the false-positive rate was 1.11 (95% CI: 0.89–1.37)/patient-year during periods with an AHRE burden <1 h/day and 1.78 (95% CI: 1.32–2.35)/patient-year during periods with an AHRE burden ≥20 h/day ($P = 0.007$). In the matched non-AHRE patients, the rate of false-positive alerts was 0.87 (95% CI: 0.75–1.01)/patient-year ($P = 0.057$ vs. AHRE burden <1 h/day, $P < 0.001$ vs. AHRE burden ≥20 h/day).

Sensor data findings

Table 2 compares the average values of the HeartLogic index and its contributing sensors measured in the AHRE group. The values of the combined index, respiratory rate, and night heart rate were significantly higher during periods with an AHRE burden ≥20 h/day than during periods with an AHRE burden <1 h/day, while the amplitude of the first heart sound was lower. Similar differences were observed vs. the matched non-AHRE group, which also showed higher values of first heart sound amplitude than those recorded during AHRE burden <1 h/day. The trends in the average index and sensor values surrounding the HeartLogic alert are reported in *Figure 2*. In the weeks preceding the alert, the trends in the sensors were similar between the groups, while the absolute values of signal amplitudes seemed to differ for a long time before the alert. Following the alert onset, the combined index persisted at higher values for a longer time when the AHRE burden was ≥20 h/day.

Discussion

This study showed that patients with the multi-sensor ICD monitoring algorithm received more HF alerts during periods of long-lasting atrial arrhythmias. The ability of the algorithm to identify periods of increased risk of HF events persisted during AF, although its risk stratification performance was lower than during non-AF periods and in non-AF patients.

Atrial fibrillation is frequent in HF.[14,21] Heart failure and AF can cause or exacerbate each other through mechanisms such as structural cardiac remodelling, activation of neurohormonal systems, and rate-related left ventricular impairment.[22] Indeed, the development of AF in patients with chronic HF is associated with a worse outcome, including stroke and increased mortality.[15,16] Moreover, cases of AF coexisting with HF require specific therapeutic management.[23] Indeed, although relieving congestion may reduce sympathetic drive and ventricular rate and increase the probability of spontaneous return to sinus rhythm, the presence of AF may reduce the prognostic benefits of HF therapies.[24,25] For these reasons, AF patients could be those who benefit most from the addition of advanced tools for remote disease management. Modern ICD algorithms designed to provide early warning of changes in HF status combine data from multiple sensors, which record parameters (heart rate and respiratory rate, rapid shallow breathing index, third and first heart sounds, thoracic impedance and activity) that are objective measurements of the underlying pathophysiology associated with signs and symptoms of worsening HF.[26–32] The HeartLogic index has displayed high sensitivity and the ability to identify periods when patients are at significantly increased risk of worsening HF.[9,13,33–36] However, in patients with AF, a different performance of the diagnostic algorithm cannot be excluded. Current guidelines for the diagnosis and management of AF consider the clinical significance of AHRE

Table 2 Comparison of average values of HeartLogic index and contributing sensors

		HeartLogic index	S3 amplitude (mG)	S1 amplitude (mG)	Thoracic impedance (ohms)	Respiratory rate (breaths/min)	Night heart rate (bpm)	Activity (min)
	AHRE ≥20 h	14.9 ± 10.5	1.0 ± 0.3	1.8 ± 0.8	44.9 ± 8.6	18.2 ± 2.2	75.4 ± 9.5	86.2 ± 59.6
	AHRE <1 h	7.3 ± 5.1	0.9 ± 0.2	2.1 ± 0.8	45.4 ± 7.1	17.7 ± 1.9	68.2 ± 6.7	88.2 ± 54.6
P-value		<0.001	0.058	<0.001	0.456	0.016	<0.001	0.688
Matched non-AHRE		5.7 ± 4.8	0.9 ± 0.2	2.5 ± 0.9	47.3 ± 8.7	17.3 ± 2.1	66.1 ± 8.4	104.7 ± 54.3
P-value	vs. AHRE ≥20 h	<0.001	0.014	<0.001	0.104	0.014	<0.001	0.052
	vs. AHRE <1 h	0.060	0.183	0.023	0.171	0.311	0.122	0.073

AHRE, atrial high-rate episode.

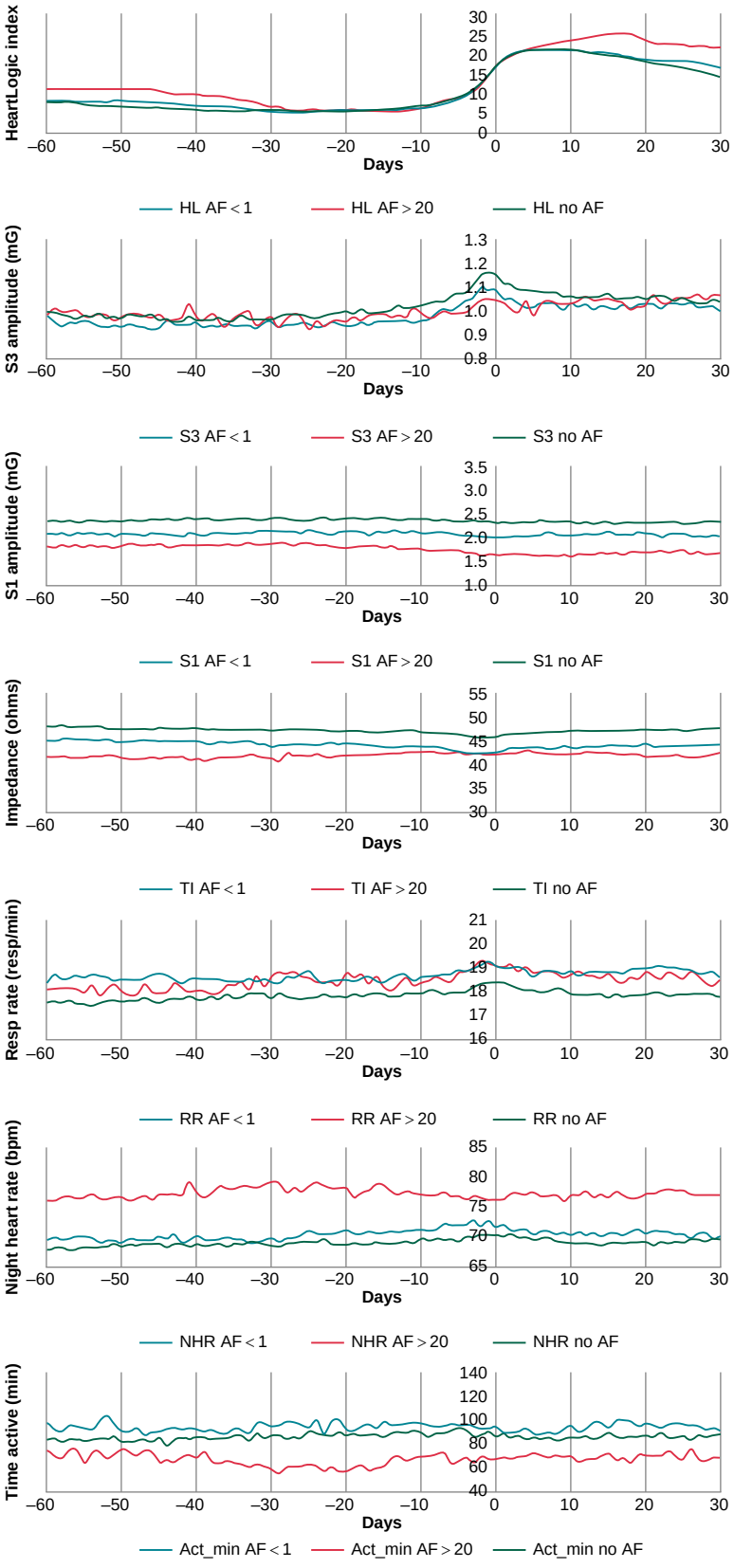


Figure 2 HeartLogic index and its contributing sensors: average data collected by devices at the time of alerts in the atrial high-rate episode (AHRE) group during periods with AHRE burden ≥20 h and AHRE burden <1 h, and during follow-up of the matched non-AHRE group (day 0 is the day when the HeartLogic index crossed the threshold).

and subclinical AF.[37] Very short device-detected AHREs (<5 min) are usually considered clinically irrelevant, but longer episodes are associated with an increased risk of clinical AF, ischaemic stroke, major adverse cardiovascular events, and cardiovascular death.[38–40] AHRE of longer duration, in the range of hours, display a higher probability of progressing to duration ≥23 h.[41] Moreover, progression to persistent/permanent AF is associated with adverse cardiovascular events, hospitalizations, and death,[42] but it is unclear whether AF progression is a determinant of adverse prognosis or rather a marker of an underlying progressive disease/substrate.[43–46] Risk factors for AF progression include age, chronic kidney disease, and chronic pulmonary diseases.[47] Indeed, we recorded significant differences in these variables between patients in the AHRE and unmatched non-AHRE groups, but were able to minimize them by means of propensity score matching. In our study, we considered long periods (a median duration of 95 days) characterized by an AHRE burden ≥20 h/day. This allowed us to evaluate the performance of the algorithm during long-lasting episodes of atrial arrhythmia, rather than the immediate impact of AF onset on specific ICD sensors and the combined index. For methodological reasons, we limited our analysis to the subgroup of patients who also experienced periods of consistent sinus rhythm, in order to allow intra-patient comparisons.

In our study, the overall rate of alerts was similar to that recorded in the MultiSENSE study,[9] when the nominal HeartLogic threshold value of 16 was set. During periods with an AHRE burden ≥20 h/day, we found a higher alert rate and a longer duration of the alert state. Moreover, in the matched non-AHRE group, the alert rate was lower than in the study group when periods with an AHRE < 1 h were considered, suggesting some propensity for alerts to be issued even in conditions of minimal or no AF burden. The differences in alert rates between periods and groups matched the differences observed in the rates of HF events.

In the specific setting of AF, our data revealed that the IN-alert or OUT-of-alert state was able to identify periods when patients were at significantly increased risk of HF hospitalizations, thus extending previous observations.[13,36]

The risk stratification ability of the HeartLogic algorithm seemed to persist during AHRE periods, although the IRR of HF hospitalizations was higher during periods with minimal/no AHRE and in non-AHRE patients. Moreover, the false-positive rate seemed slightly higher during AHRE periods, although it was in line with the value reported in the seminal MultiSENSE study.[9] This seems intuitive, as during AF fewer independent components that are not directly affected by the arrhythmia are available for the evaluation of the combined index. While detection of the atrial arrhythmia is not, by itself, a component of the combined risk score, the night heart rate contributes to the calculation of the index and is directly impacted by the arrhythmia.

According to the literature, alternative multi-parametric HF risk scores are obtained by combining different ICD-measured variables. A recent study investigated the HF risk stratification ability of an index based on seven parameters, including AHRE burden and another four heart rate-based parameters: daily heart rate, night rate, rate variability, and the number of premature ventricular complexes.[10] Another ICD monitoring system is based on the combination of multiple heart rate-derived variables (AHRE burden, ventricular rate during AF, night heart rate, heart rate variability, percentage of CRT pacing) and a few other rate-independent variables (thoracic impedance, patient activity, treated ventricular arrhythmias).[8,32] The fact that most components of these HF scores are derived from heart rate assessment suggests that they could be less robust in the presence of long-lasting AF. Indeed, the validation study of the first of the two algorithms mentioned above[10] excluded patients with permanent AF, and its commercial diagnostic function is contra-indicated for patients in permanent AF or with no atrial lead implanted. Nevertheless, as no specific validation of these systems in patients with permanent AF has been performed, any hypotheses require verification.

The HeartLogic algorithm allows the index threshold to be customized, which, as demonstrated in the MultiSENSE study,[9] can improve sensitivity or, alternatively, minimize unexplained alerts. Moreover, Gardner *et al.*[13] demonstrated that its risk stratification performance was high over the entire range of configurable thresholds, with limited variability of the HF event rate ratio. Therefore, although the rate of alerts does not seem so high as to generate a critical workload in terms of patient management at clinical centres, the possibility of increasing the index threshold during AHRE could be considered, as this might reduce the HF alert rate to the level observed in the absence of AHRE. This option should be the subject of prospective evaluations.

In our analysis of the average sensor values, we noted a higher nocturnal heart rate, a higher respiratory rate, and a lower first sound amplitude during AHRE periods. We also recorded higher values of first sound amplitude in the non-AHRE group than in the AHRE group, even during periods with an AHRE burden <1 h/day. This may reflect better clinical conditions among non-AHRE patients, despite the good match of baseline clinical variables between the groups, and could explain the observed lower rate of HF alerts. Indeed, lower first sound amplitudes are indicative of greater impairment of the systolic function[28] and may be able to predict AF progression. Our analysis of sensor values showed that, despite the differences in absolute values, the trends in these values at the time of the alerts were similar between conditions and groups, suggesting that the mechanism triggering the HF event was comparable, regardless of the heart rhythm condition. The higher average value of the combined index during AHRE periods long before the alert was a consequence of the higher alert rate, i.e. the higher probability that a previous event had occurred, while the persistence of high index values after the alert suggests slower clinical recovery and has been shown to be associated with less effective treatments and with the need for hospital admission for further treatments.[48] Previous studies suggested that patients with AF at implantation might be more exposed to HeartLogic alerts[49] and used the physiologic sensor data of the algorithm to investigate the temporal relationship between HF and AF.[50,51] Unlike our study, which analysed long-lasting AF episodes, the secondary analysis of the MultiSENSE study[51] focused on sensor changes at the time of AF onset. The authors reported that ICD-measured HF indicators worsened before the onset of AF and that the HF status worsened further, and the risk of HF events increased following AF, thus highlighting the bidirectional interaction between AF and HF. Since many HF patients with reduced ejection fraction are indicated for a cardiac device, the availability of an algorithm with proven risk stratification ability provides an opportunity for the ambulatory monitoring of HF also in the presence of AF.

Limitations

Our study has some limitations. First, its retrospective design may have introduced an inherent bias. Secondly, the onset of AF can affect the performance of the multi-sensor algorithm in several ways. It may directly affect some of the contributing sensors (e.g. increased heart rate), trigger an actual worsening of the HF detected by the system, or affect the accuracy with which sensor data are measured. Our analysis did not clarify what determines the higher alert rate during AF; we only assessed the overall performance of the algorithm and speculated on the possible mechanism involved. Thirdly, device-detected AHRE are a surrogate of subclinical—and non-clinical—AF, which has different clinical implications. However, to evaluate the performance of the algorithm in stable conditions in the presence and absence of atrial arrhythmia, we considered extremely long durations (at least 30 consecutive days) for the definition of AHRE periods, thereby probably excluding any possibility of different natures of the episodes.

Conclusions

In ICD patients monitored by means of this multi-sensor algorithm, HF alerts were more frequent during periods of long-lasting atrial arrhythmia. The ability of the algorithm to identify periods of increased risk of

HF events persisted during AF, although its risk stratification performance was lower than during non-AF periods and in non-AF patients. The presence of AHRE was associated with HF hospitalizations.

Supplementary material

Supplementary material is available at *Europace* online.

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Data availability

The experimental data used to support the findings of this study are available from the corresponding author upon reasonable request.

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