

Before multi-lead electrocardiogram (ECG) systems were readily available a significant amount of research was performed into the optimal placement of bipolar ECG electrodes for ambulatory and exercise ECG monitoring. However, bipolar chest leads (BCLs) are used rarely nowadays. In recent years, a number of patch based ECG devices have emerged focused on continuous rhythm monitoring. ECG patches typically record a single BCL but are constrained by small inter-electrode distances making some ECG features, such as P-waves, difficult to detect. In this study we aim to determine new BCLs at a range of small inter-electrode distances for maximum P-wave and QRS amplitude, providing optimal patch locations for long-term ECG rhythm monitoring.

The study data consisted of 120-lead BSPMs recorded from 744 patients (229 healthy, 278 MI, 237 LVH). The dataset was then randomly split into a training dataset of 560 patients and a testing dataset of the remaining 184 patients. To improve spatial resolution, the 120-lead were expanded to 352 nodes which correspond to the nodes of the Dalhousie torso. An exhaustive lead selection method was applied to each map from which 61,776 unique bipolar ECG leads were established for each patient. Inter-electrode distances for each lead was then calculated from the Euclidean distance between nodes on the Dalhousie torso model. Maximum P-wave and QRS amplitudes were calculated from each lead and median values taken across the training population. New BCLs were then determined at inter-electrode distances of 1, 2, 3 and 4 in. and compared to the Mason-Likar (ML) Limb leads and the current standard ECG patch location (below the left sternoclavicular joint towards the left nipple).

There was a strong linear relationship between inter-electrode distance and median ECG amplitude achieved for both the P-wave ($R = 0.98$) and QRS complex ($R = 0.93$). Generally, the best performing BCLs for P-wave amplitude were located on or just above precordial leads V1 and V2. For the QRS complex, electrodes placed horizontally between the third and fourth left intercostal space provided the greatest QRS amplitude.

This study provides a definition of the optimal placement of bipolar ECG patches for P-wave and QRS-complex signal amplitude, at specific inter-electrode distances. The demonstrated improvement in signal magnitude may lead to more accurate rhythm monitoring using ECG patches by reducing the amount of false positive alarms due to high signal-noise.

Table 1

ECG amplitudes from new bipolar chest leads compared to the Mason-Likar Limb Leads and the currently used ECG patch location.

Lead	P-wave amplitude (μV)	QRS amplitude (μV)
Current patch placement	16 [0–41]	458 [20–1206]
BCL _{P1}	30 [2–92]	180 [8–675]
BCL _{P2}	55 [0–124]	145 [0–1005]
BCL _{P3}	89 [9–167]	413 [8–1619]
BCL _{P4}	105 [9–188]	467 [9–1692]
BCL _{QRS1}	14 [0–41]	621 [68–1629]
BCL _{QRS2}	27 [4–68]	1006 [100–3254]
BCL _{QRS3}	36 [10–96]	1576 [265–4601]
BCL _{QRS4}	42 [10–107]	1784 [265–4602]
ML I	17 [0–61]	172 [35–712]
ML II	128 [22–216]	982 [107–2718]
ML III	52 [2–134]	485 [7–816]

Values represent median and [96% range].

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Improved AF rhythm discrimination using QRS morphology

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Background: Implantable cardiac monitors (ICMs) are valuable tools for long-term ECG monitoring, especially for AF. However, AF detection algorithms based solely on R-R interval variability are prone to a high number of false positives due to ectopic beats and noise.

Objective: The purpose of this analysis is to report on the simulated performance of an AF algorithm when using QRS morphology information.

Methods: Twelve-lead ECG data from 487 patients from 6 different clinical studies (collected in both in-clinic and ambulatory settings), including 35 AF patients, were used to evaluate the AF algorithm. The ECG vector V2–V3 was used to approximate the implanted ICM electrode configuration. The algorithm made a classification of AF or Non-AF for every 2-min window.

Morphology Evaluation: The V2–V3 signal morphology of each detected beat in the 2-min window was compared against a QRS template built during sinus rhythm. A match score was assigned to each beat based on the similarity to the template. The percentage of mismatched beats per 2-min window (for example, due to noise or ectopic beats) was used to determine the degree of R-R interval variability not associated with AF. The user-programmed levels for ectopy rejection and AF sensitivity will determine the thresholds used to reject potential AF rhythms.

Results: A total of 44,716 2-min windows were evaluated. Morphology information was available in 228 windows of true AF along with 51 windows of false positives for AF. Morphology assessment was not conducted for 4 patients in persistent AF throughout the data recording (i.e. no sinus rhythm). Using the morphology evaluation, the results ranged from 41.2% reduction in false positives (21/51 windows) with no impact on sensitivity, to 56.9% (29/51 windows) reduction in false positives with a cost of missing 5 true AF windows (97.8% sensitivity) depending on how the ectopy rejection level is tuned.

Conclusions: Assessment of EGM morphology in an ambulatory AF detection algorithm can meaningfully reduce false positives with minimal impact to sensitivity.

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Bayesian analysis of a new cardiac electrical biomarker

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Background: A new cardiac electrical biomarker (CEB) has been identified with reportedly high diagnostic accuracy in the detection of acute myocardial ischemic injury (AMII). The CEB is constructed continuously in real-time from an electrocardiogram (ECG)/cardiac monitoring device (VectraplexECG System, VectraCor Inc, Totowa, NJ).

Objective: Perform a Bayesian analysis of the predictive value of the CEB based on changes in prevalence of disease.

Methods: Data from 316 original CEB study test case ECGs were retrospectively reviewed and a Bayesian analysis was performed to construct the predictive value curves of positive and negative CEB test results in the detection of AMII. The original study gold standard was based on adjudicated physician interpretations of initial 12-lead ECGs acquired from patients presenting with chest pain. The CEB is constructed from a 12-lead derived ECG (dECG). The dECG is synthesized from 3 leads {I, aVF, V2} of the standard 12-lead ECG. The prevalence of AMII in this study population was 21.2%. A subsequent CEB post-marketing study of 138 patients was performed for which Bayesian analysis predictive value curves were also constructed. In this follow-up study the serum troponin I was the gold standard for detection of AMII yielding a prevalence of disease of 13%. The posterior vs. prior probability Bayesian curves of the CEB positive and negative predictive values were compared for actual, worst case and best case scenarios. Area between the curves was used for the statistical analysis using the Mann-Whitney U test. Diagnostic accuracy parameters included sensitivity (Sn), specificity (Sp), negative and positive predictive values (NPV, PPV), and likelihood ratios (LR+, LR-).

Results: No statistically significant differences were noted at $p < 0.05$ between the 2 independent CEB Bayesian analysis area between the curves for the actual, worst and best case scenarios. The actual data diagnostic accuracy parameters for each study were as follows:

Actual data	Sn	Sp	NPV	PPV	LR+	LR-
Original	0.922	0.913	0.977	0.747	10.598	0.085
Follow-up	0.895	0.953	0.981	0.773	18.968	0.110

Conclusions: The Bayesian CEB predictive value curves appear to be similar between the 2 independent studies that had different prior probabilities of AMII. This suggests that the ROC cut-offs chosen for detection of AMII may be accurate. Further studies are needed to validate these findings.

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Diurnal dynamics of short-term variability of the QT-interval in a primary prevention ICD-population

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Background: Short-term variability of the QT-interval (STV-QT) has shown to be associated with an increased risk of ventricular arrhythmias. However, little is known about the diurnal behaviour of STV-QT. Furthermore, it is not known whether a certain time point might be more sensitive to identify the patient at risk. Therefore, we aim to investigate if a.) STV-QT behaves in a circadian pattern and b.) if this behaviour differs between high and low risk patients.

Methods: As part of the EU-CERT-ICD study, 24 h ambulatory Holter recordings were performed in patients receiving an ICD for primary prophylactic indication. Since clinical end points (e.g. appropriate shocks) are not yet known, patients were categorized based on their arrhythmia score (AS), a custom-made weighted score of the number of arrhythmic events on the recording. STV-QT was calculated for every hour in a random sample of 15 patients with high AS (>1000 arrhythmic events in 24 h) and 15 patients with low AS (<100 arrhythmic events in 24 h).

Results: The overall dynamicity of STV-QT showed high intra- and interindividual variability, with a peak in the early morning (8.00 h) and in the late afternoon (18.00 h). When the patients were categorized based on their AS, the circadian pattern of STV-QT differed between patients with high and low AS. Patients with high AS showed a significant higher STV-QT compared to patients with low AS at both 8.00 h (1.22 ± 0.55 vs 0.60 ± 0.24 , $p < 0.01$) and 18.00 h (1.12 ± 0.39 vs 0.64 ± 0.29 , $p < 0.01$).

Conclusion: STV-QT displays a peak in the early morning and late afternoon, mainly in patients with a high AS. This increase of STV-QT at waking hours might reflect an increased risk of arrhythmias at that moment during the day. Determination of STV-QT at these time points might thus be more sensitive in identifying patients at high risk of ventricular arrhythmias.

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Ensemble tree classifier to identify root causes of false alarms at hospital level

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Background: Medical devices' alarm have high sensitivity to minimize the risk of missing adverse events. This results in many alarms - up to hundreds per patient per day in clinical units such as the ICU and ED. Many of these are clinically irrelevant. The problem is further exacerbated

by the fact that the vast majority are false alarms (86–99%), resulting in reduced patient safety and staff satisfaction. Here we develop a novel algorithm to identify and report statistics on features from the originating signals indicative of preventable non-physiological events that ultimately lead to false alarms such as poor electrode placement.

Methods: We train an ensemble tree on multiple-expert annotated ECG alarms (training = 6602; test = 1651). We then use a reverse mapping approach on the nodes to identify the actionable root causes of each false alarm. To determine significant features for a single alarm, for each tree we identify all of the relevant nodes and account for the importance of each node to determine its contribution to the alarm being classified as a false positive. For each false alarm, we then sum over all the trees to get scores for all of the features and threshold. Finally, we count the number of instances that each feature results in false alarms at a hospital level.

Results: The classifier resulted in a high sensitivity and specificity: 82.5% and 93.4%, respectively, (ROC AUC = 0.94). This tackles the joint task of binary classification of true and false alarms and identification of features triggering false alarms. In the training set, we found the primary actionable drivers of false alarms at the study hospital and suggest corresponding actions that could prevent them in the future: patient motion and respiration (mild skin abrasion or gritty gel), muscle tremor (move electrode to avoid culprit muscle), intermittent or missing leads (alcohol wipe or hair removal at electrode site), and gain (adjust monitor settings).

Conclusion: Here we develop a classifier that has both high performance in differentiating false alarms from true alarms and can assist in identifying drivers of the identified false alarms. This approach is advantageous as it allows the hospital to develop a custom strategy for alarm management that accounts for their unique patient population, staff behaviors and preferences, available resources, and the clinical environment. We believe this data-driven approach can assist hospitals in developing tailored solutions to better tackle alarm fatigue.

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Pathological S-wave in lead I in left bundle branch block is associated with MRI scar and reduced left ventricular function

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Background: The 2009 electrocardiographic Selvester QRS score for LBBB (2009 LBSS) is prognostic in CRT-patients. Previous studies show limited diagnostic performance in detecting and quantifying left ventricular (LV) scar determined by cardiovascular magnetic resonance imaging (CMR). We aimed to develop an improved method for ECG detection of scar using a large and broadly selected dataset of patients with LBBB.