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A new ECG marker to identify patients at low risk for ventricular tachyarrhythmias: SAI QRST

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Abstract

Objective—We proposed and tested a novel ECG marker of risk of ventricular arrhythmias (VA).

Methods—Digital orthogonal ECGs were recorded at rest before ICD implantation in 508 participants of a primary prevention ICDs prospective cohort study (mean age 60 ± 12 ; 377 male [74%]). The sum magnitude of the absolute QRST integral in 3 orthogonal leads (SAI QRST) was calculated. A derivation cohort of 128 patients was used to define a cutoff; a validation cohort ($n=380$) was used to test a predictive value.

Results—During a mean follow-up of 18 months, 58 patients received appropriate ICD therapies. SAI QRST was lower in patients with VA (105.2 ± 60.1 vs. 138.4 ± 85.7 mV*ms, $P=0.002$). In the Cox proportional hazards analysis, patients with SAI QRST ≤ 145 mV*ms had about 4-fold higher risk of VA (HR 3.6; 95% CI: 1.96–6.71, $p<0.0001$), and a 6-fold higher risk of monomorphic ventricular tachycardia [MMVT] (HR 6.58; 95% CI 1.46–29.69, $P=0.014$), whereas prediction of polymorphic ventricular tachycardia or ventricular fibrillation did not reach statistical significance.

Conclusion—High SAI QRST is associated with low risk of sustained VA in patients with structural heart disease.

Sudden cardiac death (SCD) strikes about 350,000 victims in the United States every year.¹ Implantable cardioverter-defibrillators (ICDs) are the treatment of choice^{2–4} for patients at risk for SCD. The need to extend risk stratification beyond use of ejection fraction is well recognized.^{5, 6} A U-shaped curve for ICD benefit was shown in the analysis of the MADIT II study,⁵ prompting a search for markers that identify low-risk patients who do not benefit from ICD implantation.

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During the century of electrocardiography multiple attempts were made to decipher complex information carried by cardiac electrical signal to obtain important clinical diagnostic and prognostic information. Several approaches have been proposed to develop composite ECG metrics that account for both amplitude and duration of ECG waveforms, with the goal to diagnose hypertrophy^{7, 8}, to determine localization and size of the scar⁹⁻¹¹, and to assess heterogeneity of action potential¹². Although modern imaging modalities question utility of diagnostic ECG, prognostic ECG markers remain of interest. Arrhythmogenic substrate in susceptible to ventricular arrhythmia (VA) patients with structural heart disease is characterized by specific electrophysiological properties of a scar, cardiac hypertrophy and dilatation, resulting in the conditions of source-sink mismatch^{13, 14} and dispersion of refractoriness¹⁵⁻¹⁷.

In this work we proposed a novel ECG metric, sum magnitude of the absolute QRST integral (SAI QRST). We hypothesized that the SAI QRST predicts VA in primary prevention ICD patients with structural heart disease.

Methods

The study protocol was approved by the Johns Hopkins University IRB, and all patients gave written informed consent before entering the study.

Study population

PROSE-ICD (NCT00733590) is a prospective observational multicenter cohort study of primary prevention ICD patients with either ischemic or non-ischemic cardiomyopathy. Patients were eligible for the study if the left ventricular (LV) ejection fraction (EF) was less than or equal to 35%, myocardial infarction was at least 4 weeks old, or non-ischemic LV dysfunction was present for at least 9 months. Patients were excluded if the ICD was indicated for secondary prevention of SCD, if patient had a permanent pacemaker or a Class I indication for pacing, if the patient had NYHA class IV, or if the patient was pregnant. Electrophysiologic testing to assess inducibility of VT was performed in 373 patients (73%) at the time of ICD implantation. Left ventricular diastolic diameter (LVDD) was assessed by two-dimensional echocardiography in 225 patients (44.3%). Single-chamber ICD was implanted in 263 patients (52%), dual-chamber ICD in 92 patients (18%), and cardiac resynchronization therapy defibrillator (CRT-D) in 153 patients (30%). The PROSE-ICD study is an ongoing active project that continues to enroll new patients. This report presents data analysis of study participants with at least 6 months of follow-up, recruited at the Johns Hopkins Hospital site.

Surface ECG recording

Digital orthogonal ECG was recorded before ICD implantation during 5 minutes at rest, using the modified Frank orthogonal XYZ leads¹⁸ by PC ECG machine (Norav Medical Ltd, Thornhill, ON, Canada), with a 1000 Hz sampling frequency, high-pass filter 0.05 Hz, low-pass filter 350 Hz, and notch filter 60Hz.

QRST integral measurement

All ECGs were analyzed by customized software in a robust automated fashion. Noise and ventricular premature and ventricular-paced beats were excluded from analysis, but ECG recordings during atrial fibrillation were analyzed. Images of areas under the QRST curve were reviewed to ensure appropriate ECG wave detection. Absolute QRST integral was measured as the arithmetic sum of areas under the QRST curve (absolute area under the QRST curve above baseline was added to the area below baseline, Figure 1), averaged

during a 5-min epoch. The sum magnitude of 3 orthogonal leads absolute QRST integral (SAI QRST) was calculated.

Endpoints

Appropriate ICD therapies [either shock or antitachycardia pacing (ATP)] for VA served as the primary endpoint for analysis. Programming of the ICD was based on the attending electrophysiologist's clinical evaluation. The ICD device was interrogated during follow-up visits every 6 months. All ICD interrogation data were reviewed by an independent endpoints adjudication committee, blinded to the results of SAI QRST analysis. ICD therapies for monomorphic ventricular tachycardia (MMVT), polymorphic ventricular tachycardia (PVT), or ventricular fibrillation (VF) were classified, as appropriate. MMVT was defined as a sustained VT with stable cycle length and electrogram morphology. PVT was defined as a sustained VT with unstable cycle length and electrogram morphology and average cycle length ≥ 200 ms. VF was defined as sustained ventricular tachyarrhythmia with unstable cycle length and electrogram morphology and average cycle length <200 ms. Sustained appropriately treated VT/VF events were categorized as MMVT group and PVT/VF group.

Statistical analysis

The first 128 consecutive participants of the PROSE-ICD study were included in the derivation cohort. The validation cohort included the remaining 380 PROSE-ICD study participants who were followed prospectively at least 6 months.

Derivation dataset analysis—Cut-off points of SAI QRST were determined in the preliminary analysis of 128 study patients, 15 of whom had sustained VT/VF events during 13 ± 10 months of follow-up. In this derivation set the lowest SAI QRST quartile was ≤ 69 mV*ms, and the highest quartile was >145 mV*ms. Preliminary survival analysis of the derivation set showed that the lowest quartile of the SAI QRST predicted VT/VF (log rank test $P < 0.0001$) with 100% sensitivity, 78% specificity, 37% positive predictive value, and 100% negative predictive value.

Validation dataset analysis—Validation cohort participants were categorized according to their baseline SAI QRST value, with SAI QRST ≤ 69 mV*ms labeled *low*, SAI QRST 70-145 mV*ms labeled *intermediate*, and SAI QRST >145 mV*ms labeled *high*. Linear regression analysis was used to study what physiologic parameters correlate with the SAI QRST. One-way ANOVA was used to compare among 3 groups of SAI QRST, with Bonferroni correction for multiple comparisons. Unadjusted and adjusted Kaplan-Meier survival curves were constructed for subjects with low, intermediate, or high SAI QRST. The log-rank (Mantel-Cox) statistic was computed to test the equality of survival distributions. Univariate and multivariate Cox proportional hazards regression analyses were performed. An interaction between SAI QRST and bundle branch block (BBB) status, as well as between SAI QRST and LVDD, was tested in the Cox model. The receiver operating characteristic (ROC) curves with area under the curve (AUC), sensitivity, specificity, and predictive values of SAI QRST for freedom from VT/VF were calculated. STATA 10 software (StataCorp LP, College Station, TX) was used for calculations.

Results

Patient population

Clinical characteristics of the derivation and validation cohort patients are outlined in Table 1. There were no statistically significant differences between baseline characteristics of the two cohorts. Neither did the rate of VT/VF events differ significantly (15 patients (11.7%) in

derivation cohort vs. 43 patients (11.3%) in validation cohort experienced VT/VF; $P=0.901$). A few differences in patient management were observed: derivation cohort patients were more frequently on beta-blockers and statins, with a slightly higher rate of revascularization procedures.

Ventricular tachyarrhythmias during follow-up

During a mean follow-up of 18.0 ± 16.5 months, 43 (11.3% or 7.5% per person-year of follow-up) of the 380 validation cohort patients experienced sustained VA and received appropriate ICD therapies. MMVT with an average cycle length (CL) of 293 ± 38 ms was present in 31 patients (72%). PVT/VF with an average CL 214 ± 18 ms was documented in 12 patients (3.2% or 2.1% per person-year of follow-up). There were significantly fewer patients on beta blockers among those patients receiving subsequent appropriate ICD therapies (Table 2).

Predictive value of SAI QRST in validation cohort

Representative examples of baseline SAI QRST ECG in a patient with and one without subsequent sustained ventricular tachyarrhythmia and appropriate ICD therapy at follow-up are shown in Figure 2. SAI QRST was significantly lower in patients with sustained VA during follow-up (Wilcoxon rank-sum test $P=0.004$ and Student's t -test $P=0.002$) [Figure 3]. Kaplan-Meier survival analysis showed that the SAI QRST was significantly predictive for freedom from VT/VF during follow-up (Figure 4A).

In the univariate Cox proportional hazards analysis, patients with high SAI QRST had a 41% decrease in risk of VA compared to patients with intermediate SAI QRST, and accordingly patients with intermediate SAI QRST had a 41% decrease in risk of VA compared to patients with low SAI QRST (hazard ratio for variable “low-intermediate-high SAI QRST” (HR) 0.59; 95% confidence interval (CI): 0.39-0.89, $P=0.012$). SAI QRST predicts MMVT (HR 0.45; 95% CI 0.20-0.99; $P=0.049$), rather than PVT/VF (HR 0.65; 95% CI 0.40-1.06; $P=0.085$). Importantly, the risk of VA in patients with low or intermediate SAI QRST was 4-fold higher, than in patients with high SAI QRST (HR 4.05; 95% CI: 2.00-8.20, $P<0.0001$). Risk of MMVT was more than 6-fold higher (HR 6.58; 95% CI 1.46-29.69, $P=0.014$) [Figure 4B]. However, prediction of freedom from PVT/VF with high SAI QRST did not reach statistical significance (HR 0.16; 95% CI 0.021-1.25; $P=0.080$) [Figure 4C].

Low, intermediate, and high SAI QRST

Characteristics of the patients with low, intermediate, and high SAI QRST are presented in Table 3. There were more non-ischemic cardiomyopathy patients with low LVEF, and at the same time more patients with bundle branch block and implanted CRT-D device among the high SAI QRST group. Patients with low SAI QRST had higher body mass index and were more frequently diagnosed with ischemic cardiomyopathy.

Several parameters were statistically significantly correlated with the SAI QRST: age ($r=0.115$, $P=0.010$), LVDD ($r=0.138$, $P=0.009$) [Figure 5A], EF ($r=-0.162$, $P=0.0001$) [Figure 5B], body mass index ($r=-0.102$, $P=0.024$) [Figure 5C], duration of the QT interval ($r=0.274$, $P<0.0001$) [Figure 5D], heart rate ($r=-0.101$, $P=0.022$) [Figure 5E], beat-to-beat QT variability index¹⁹ ($r=-0.176$, $P<0.0001$), and QRS width ($r=0.634$, $P<0.0001$) [Figure 5F]. SAI QRST was significantly higher in patients with either left or right complete BBB (212.5 ± 100.8 vs. 109.4 ± 56.62 , $P<0.00001$), and it was diminished in patients with ischemic cardiomyopathy (121.86 ± 67.48 vs. 150.45 ± 96.52 , $P=0.0002$).

Multivariate survival analysis in validation cohort

Among other clinical and ECG parameters, use of beta-blockers, implanted CRT-D device and LVDD > 6cm were significant in the univariate Cox regression for prediction of VA. Neither QT nor QRS duration predicted VT/VF events. Ejection fraction with cut-offs 20, 25 and 30% was not associated with the risk of VA.

No significant interaction was found between SAI QRST and presence of BBB, or between SAI QRST and LVDD. In the multivariate Cox regression analysis for VT/VF events, high SAI QRST remained a significant predictor of freedom from VT/VF after adjustment²⁰ for the use of beta-blockers, implanted CRT-D, LVDD, and LV EF. The most complete multivariate Cox regression model for VT/VF prediction is shown in Table 4. Use of beta-blockers and LVDD > 6cm remained significant predictors in the multivariate model too.

The ROC curve measuring the accuracy of the SAI QRST for freedom from VT/VF showed an AUC of 0.628 (95% CI: 0.538-0.717) [Figure 6A]. SAI QRST ≤ 145 mV*ms demonstrated 79% sensitivity, 65% specificity, 14% positive predictive value, and 93% negative predictive value for prediction of VA during 1.5 years of follow-up.

SAI QRST and QRS width

No significant interaction was found between SAI QRST and the presence of BBB in the multivariate Cox regression model. This outcome means that the SAI QRST predicts VT/VF in patients with and those without BBB. However, SAI QRST was significantly larger in patients with either left or right complete BBB (212.51 ± 100.8 vs. 109.35 ± 56.62 , $P < 0.00001$). Therefore, we suggest that the best cut-off value of SAI QRST should be different for patients with wide vs. narrow QRS. For the purpose of this analysis we combined derivation and validation cohorts and categorized all 508 study patients as part of either the *narrow QRS* subgroup (QRS ≤ 120 ms, N=272, [53.5%]) or the *wide QRS* subgroup (QRS > 120 ms, N=236 [46.5%]). To define the best SAI QRST cutoff value, ROC curves were constructed separately in patients with narrow and patients with wide QRS (Figures 6B and 6C). In patients with narrow QRS ≤ 120 ms the SAI QRST of 82 mV*ms provided 60% sensitivity and 55% specificity. In patients with wide QRS > 120 ms the SAI QRST of 138 mV*ms provided 64% sensitivity and 70% specificity. A test on the equality of ROC areas between patients with narrow and those with wide QRS did not show a statistically significant difference.

SAI QRST in CRT-D patients

Both derivation and validation cohorts patients were included in this analysis. VT/VF events were less frequent in CRT-D recipients, as compared with ICD patients (Log rank test $P=0.017$) [Figure 7A]. There was no statistically significant difference in the MMVT rate between ICD and CRT-D patients. However, PVT/VF was observed in 7 patients with single-chamber ICD (3.7%) and 4 patients with dual-chamber ICD (5.2%), but in only 1 CRT-D patient (0.9%) [Log rank test $P=0.017$]. In univariate Cox regression analysis risk of sustained VT/VF was lower in patients with implanted CRT-D device than in ICD patients (HR 0.45; 95% CI 0.24-0.88; $P=0.020$).

Baseline SAI QRST predicted sustained VA events in CRT-D patients (Figure 7B). In multivariate Cox regression analysis (all patients cohort) in the model that included SAI QRST, presence of BBB, use of beta blockers, LVDD, and type of device (CRT-D or ICD), SAI QRST < 145 mV*ms was associated with 4-fold higher risk of VA (HR 4.13; 95% CI 1.96-8.72; $P < 0.0001$), use of beta blockers reduced the risk of VA (HR 0.286; 95% CI 0.131-0.623; $P=0.002$), and presence of BBB was associated with 3-fold higher risk of VA (HR 2.91; 95% CI 1.38-6.13; $P=0.005$).

Discussion

In this study we present a new marker of low risk of ventricular tachyarrhythmias and show that SAI QRST >145 mV*ms is associated with a low risk of arrhythmia in structural heart disease patients with implanted ICD for primary prevention of sudden cardiac death.

Substantial evidence supports the idea that patients with structural heart disease have some degree of risk of VA during their lifetime. The strategy of identifying patients at low, rather than high, risk of VA maximizes the benefit of primary prevention ICD, excluding those at low risk of VT/VF for whom the risk/benefit ratio of the ICD, including CHF progression,²¹ is not favorable. Biostatistical studies²²⁻²⁴ have identified the requirements for a good screening test and underscored the value of ROC analysis. Hazard ratios of most commonly employed predictors of SCD²⁵ range from 2 to 4, which is insufficient for discrimination. In this analysis the SAI QRST ROC exhibited a large AUC and hazard ratio range of 4–6, as well as high sensitivity and negative predictive value, and therefore could be considered as one of the methods for screening of patients with structural heart disease to avoid ICD implantation in those at very low risk of VA.

What is SAI QRST?

The QRST integral was conceived by Wilson et al²⁶ as the time integral of the heart vector²⁷ and expresses the heterogeneity of the AP morphology.²⁸ We calculated sum absolute QRST integral, which is a different metric, not previously explored. Our choice of orthogonal ECG over 12-lead ECG was based on the advantages provided by orthogonal ECG, which permit assessment of the heart vector. Summation of absolute QRST integral of all 3 orthogonal ECG leads allows assessment of the magnitude of total cardiac electrical power and eliminates bias of single lead axis position. The precise electrophysiological meaning of SAI QRST remains to be elucidated. We speculate that (1) the low SAI QRST characterizes significant cancellation of electrical forces as an important pre-existing condition that may facilitate sustained VA; (2) low SAI QRST reflects reduced mass of viable myocardium in patients with structural heart disease; (3) SAI QRST characterizes specific geometry of the heart chambers.

Cancellation of electrical forces results in low SAI QRST

Cancellation of electrical forces in the heart may reduce ECG amplitudes. An estimated 75% of the electrical energy is canceled during ventricular depolarization,²⁹ and 92-99% is cancelled during repolarization.³⁰ Previous experiments showed that AP morphology gradients in different sites of the heart may have opposing directions and cancel out.³¹ We speculate that decrease in the sum absolute QRST integral due to cancellation coexists with the locally observed increase in APD gradients and increased native QRST integral, or “ventricular gradient”, as marker of a heterogeneity of repolarization or heterogeneity of AP morphology.^{32, 33}

SAI QRST and QRS width

Our results showed significant correlation between SAI QRST and QRS width. Consistent with previous studies^{34, 35}, we did not find a relation between ventricular conduction abnormalities and VT/VF occurrence in the cohort of all study patients. In addition, antiarrhythmic effect of CRT could affect VT/VF rate in patients with wide QRS and BBB at baseline, as about one third of our study patient population had a CRT-D device implanted. Indeed, we confirmed a statistically significantly lower rate of VT/VF events in CRT-D patients. Subgroup analysis showed that presence of BBB was a significant predictor of VT/VF events in ICD patients, but not in CRT-D patients. Although a correlation between the QRS duration and the SAI QRST is obvious, these metrics are not identical.

Notably, SAI QRST predicted VT/VF events in patients with any QRS width. Surprisingly, the predictive accuracy of SAI QRST in patients with wide QRS >120 ms was at least as good as in patients with narrow QRS ≤120ms. This important finding may lead to reevaluation of the approach to bundle branch block ECG assessment. A recent report raised the issue of reliability and reproducibility of manual QRS duration measurement.³⁶ The robust automated measurement of SAI QRST could become a reasonable alternative in future.

SAI QRST and left ventricular size

Our results revealed significant correlation between SAI QRST and LVDD. Further studies are necessary to determine the relations between SAI QRST and left ventricular geometry, hypertrophy, and dilatation. Of note, our study patients at baseline had remarkably impaired systolic function, LV dilatation, and frequently a large area of myocardial scar. Several previous studies, focused on healthier population of hypertensive patients, showed that Cornell voltage-duration product (RaVL + SV3 [+6 mm in women]*QRS duration) is associated with the risk of SCD.³⁷⁻³⁹ Interestingly, in contrast to our findings, a large instead of a small Cornell voltage-duration product was associated with the risk of SCD. Another study of patients with hypertrophic cardiomyopathy (HCM) showed that higher (not lower) ECG amplitudes and a high 12-lead QRS-amplitude sum predicts SCD in HCM patients.⁴⁰ Further studies are necessary to clarify this intriguing issue. We speculate that the SAI QRST characterizes electrical rather than geometrical characteristics of the heart, signifying cancellation of electrical forces in patients with large APD heterogeneity and high risk of life-threatening VA.

Methodology of SAI QRST

This is the first report showing the predictive value of SAI QRST. Ongoing analysis is determining whether 5 minutes of recorded ECG is necessary, or whether a shorter recorded ECG can be enough. Ongoing analysis is also making two additional comparisons: the predictive value of SAI QRST calculated from orthogonal ECG versus inverse Dower transforms derived from standard 12-lead ECG and the predictive value of the QRS amplitude versus SAI QRST.

Importantly, virtually any ECG recorded during sinus rhythm or atrial fibrillation is amenable to this analysis, thereby extending the opportunity for non-invasive VT/VF risk stratification in patient populations that would not be eligible for it otherwise.

Further studies are needed to clarify the extent to which SAI QRST reflects underlying cardiac anatomy (LV hypertrophy and/or dilatation, scar size). In this study SAI QRST remained the significant predictor in the model in the presence of the LVDD variable, thus confirming the complementary predictive value of the sum electrical forces descriptor.

Limitations

Appropriate ICD therapy as a surrogate for sudden death may overestimate the frequency of SCD.³⁵ This is a well-recognized and unavoidable limitation in the ICD era, as it would be unethical to withhold ICD therapy to study the actual death rate. The use of ICD events as the end-point for validation of a risk stratifier is frequently viewed as a weak surrogate for actual mortality. However, as soon as the VT/VF risk stratification guides the decision about whether to implant an ICD, then a risk marker that predicts the occurrence of successfully manageable by an ICD rhythms seems more appropriate than a marker that predicts events for which ICD placement would be of no benefit. At the same time, recent studies showed that patients after appropriate ICD shocks demonstrated higher mortality.²¹

Statistical power of survival analysis for primary end-point (all sustained VA events) and MMVT in this study is good. However, low rate of PVT/VF resulted in low statistical power of survival analysis with PVT/VF end-point. SAI QRST in this study did not predict PVT/VF, but it was highly predictive for MMVT in the primary prevention population of structural heart disease patients. Larger study cohort and longer follow-up are needed for conclusion regarding predictive value of SAI QRST for PVT/VF. At the same time, this preliminary finding may indicate differences in underlying mechanisms of these two types of VT and underscores the difficulties in predicting PVT/VF.

Assessment of scar, LV size and geometry was limited in this study. Further investigation is necessary to determine correlations between SAI QRST and scar size, LV mass, left ventricular hypertrophy and dilatation, and LV volumes.

In summary, SAI QRST is an inexpensive and easily measured at-rest ECG marker for the assessment of VA risk in patients with structural heart disease. High SAI QRST is associated with low risk of sustained VA.

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Figure 1.
Example of SAI QRST measurement. The sum of the areas under QRST curve on 3 orthogonal ECG leads is calculated.

Figure 2. Representative baseline SAI QRST ECG in a patient without (A) and one with (B) subsequent sustained ventricular tachyarrhythmia and appropriate ICD therapy at follow-up.

Figure 3. SAI QRST distribution in validation cohort patients without and with sustained VA at follow-up.

Figure 4.

Kaplan-Meier curves for freedom from VT/VF events in validation cohort patients with the low, intermediate, and high SAI QRST. (A) Kaplan-Meier all VT/VF events free survival; (B) Kaplan-Meier MMVT events free survival; (C) Kaplan-Meier PVT/VF events free survival.

Figure 5. Correlations between SAI QRST, body mass index (BMI) and heart function characteristics. (A) Correlation between the SAI QRST and LVDD; (B) Correlation between SAI QRST and LV EF; (C) Correlation between SAI QRST and BMI; (D) Correlation between SAI QRST and QT interval; (E) Correlation between SAI QRST and heart rate; (F) Correlation between SAI QRST and QRS width.

Figure 6. Results of ROC analysis. Receiver operating characteristic (ROC) curve on the prediction of the freedom from sustained VT/VF events. (A) for all patients; (B) for patients with narrow QRS ≤ 120 ms; (C) for patients with wide QRS > 120 ms.

Figure 7.

(A) Kaplan-Meier curves for freedom from VT/VF events in patients with the ICD and CRT-D device (N=508). (B) Kaplan-Meier curves for freedom from VT/VF events in CRT-D patients with the low, intermediate, and high SAI QRST.

Table 1

Clinical and baseline ECG characteristics of derivation and validation cohort

Characteristic	Derivation cohort (n=128)	Validation cohort (n=380)	P
Age±SD, y	59.8±10.8	60.3±12.5	0.679
Male sex, n(%)	97(75.8)	280(73.7)	0.639
Whites, n(%)	89(69.5)	267(70.3)	0.876
Ischemic CM, n(%)	65(50.8)	218(57.4)	0.194
Baseline LVEF ±SD, %	21.98±7.69	21.99±9.08	0.990
QRS, ms	124.48±34.36	120.65±31.65	0.272
Complete BBB, n(%)	28(21.9)	96(25.3)	0.440
CRT-D device, n(%)	40(31.2)	113(29.4)	0.189
LVDD±SD, cm	6.05±1.02	5.90±0.84	0.304
Body mass index ± SD	29.34±5.99	28.91±6.13	0.497
Beta blockers, n(%)	126(98.4)	356(93.7)	0.018
PTCA and/or CABG history, n(%)	86(67.2)	204(53.7)	0.045
Statins, n(%)	120(93.8)	321(84.5)	0.018
NYHA class II, n(%)	40(31.3)	110(29.0)	0.283
NYHA class III, n(%)	58(45.3)	199(52.5)	0.283
Inducible VT, n(%)	30(23.4)	93(24.5)	0.821
Heart rate±SD, bpm	72.67±14.21	73.30±14.68	0.805

Table 2

Comparison of clinical and baseline ECG characteristics of patients with and those without subsequent appropriate ICD therapy for VT/VF

Characteristic	No VT/VF events (n=337)	VT/VF events at follow-up (n=43)	<i>P</i>
Age±SD, y	60.2±12.7	60.7±11.3	0.776
Male sex, n(%)	245(72.7)	35(81.4)	0.223
White race, n(%)	233(69.1)	34(79.1)	0.180
Ischemic CM, n(%)	189(56.1)	29(67.4)	0.156
Baseline LVEF±SD, %	22.20±9.20	20.38±7.98	0.178
QRS, ms	121.57±31.92	114.05±29.07	0.122
Bundle branch block, n(%)	83(24.6)	13(30.2)	0.426
CRT-D device, n(%)	106(31.6)	7(16.3)	0.122
LVDD±SD, cm	5.86±0.96	6.41±0.71	0.026
Body mass index±SD	28.79±6.14	29.88±5.99	0.270
Beta blockers, n(%)	332(95.5)	35(81.4)	<0.0001
PTCA and/or CABG history in ischemic CM patients, n(%)	133(77.3)	16(57.1)	0.023
NYHA class II, n(%)	95(28.3)	15(34.9)	0.414
NYHA class III, n(%)	181(53.9)	18(41.9)	0.414
Heart rate±SD, bpm	72.66±14.51	69.54±15.86	0.226

Table 3

Comparison of patients with low, intermediate, and high SAI QRST

Characteristic	Low SAI QRST ≤69 mV*ms (n=71)	Intermediate SAI QRST 70 – 145 mV*ms (n=181)	High SAI QRST >145 mV*ms (n=128)	ANOVA <i>P</i>
Age±SD, y	57.6±12.9	60.0±12.5	62.0±12.0	0.057
Males, n(%)	53(74.7)	140(77.4)	86(67.2)	0.133
White race, n(%)	52(73.2)	126(69.6)	89(69.5)	0.832
Ischemic CM, n(%)	92(67.7)	90(56.3)	35(41.7)	0.008
Baseline LVEF ±SD, %	23.5±8.9	22.4±8.5	20.6±8.8	0.043
NYHA class II, n(%)	36(26.5)	46(28.8)	28(33.7)	0.555
LVDD±SD, cm	5.90±0.89	5.82±0.87	6.06±1.13	0.423
QRS, ms	97.5±14.9	111.0±25.0	147.3±30.8	<0.0001
Bundle branch block, n(%)	2(2.8)	28(15.5)	66(51.6)	<0.0001
CRT-D device, n(%)	7(9.9)	34(18.8)	72(56.3)	<0.0001
Heart rate±SD, bpm	73.4 ±15.0	73.2±14.7	70.6±14.3	0.251
QT±SD, ms	462±61	471±62	498±62	0.0001
Body mass index ± SD	30.9±7.4	28.7±5.8	28.0±5.5	0.006
Beta blockers, n(%)	62(95.4)	151(93.8)	100(92.6)	0.763
Revascularization history in ischemic CM patients, n(%)	61(67.0)	62(77.5)	26(90.0)	0.214

Table 4

Univariate and multivariate hazard ratios of tested predictors of VT/VF

Predictor	Unadjusted hazard ratio (95% CI) and <i>P</i> value	Adjusted hazard ratio (95% CI) and <i>P</i> value
Low – Intermediate – High		
SAI QRST	0.59(0.39-0.89), <i>P</i> =0.012	0.54(0.33-0.88), <i>P</i> =0.013
CRT-D device	0.42(0.17-0.94), <i>P</i> =0.035	0.68(0.29-1.58), <i>P</i> =0.369
LVDD >6 cm	3.57(1.28-10.01), <i>P</i> =0.015	3.74(1.30-10.77), <i>P</i> =0.014
LV EF ≤ 25%	1.12(0.55-2.28), <i>P</i> =0.749	1.47(0.68-3.18), <i>P</i> =0.332
Use of beta blockers	0.28(0.13-0.62), <i>P</i> =0.001	0.19(0.08-0.45), <i>P</i> =0.0001