Standard 12-lead electrocardiography measures predictive of increased appropriate therapy in implantable cardioverter defibrillator recipients

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Aims
Identification of patients most likely to benefit from implantable cardioverter defibrillator (ICD) implant remains a complex challenge. This study aimed to investigate the utility of measures derived from standard 10 s 12-lead electrocardiography (ECG) without complex signal processing in predicting appropriate therapy in an ICD population.

Methods and results
We examined 108 ICD patients for primary (n = 32) and secondary prevention (n = 76). Baseline clinical data and characteristics of QRS complex, T-wave, and heart rate from standard 12-lead ECG were examined and related to the occurrence of subsequent appropriate therapy. Over a mean follow-up of 29 ± 11 months, 44% of patients received appropriate therapy. Patients with depressed heart rate variability (HRV) (≤ 6.5%) were 2.68 [95% confidence interval (CI) 1.21–5.90, P = 0.015] times more likely to receive appropriate therapy than patients with HRV >6.5%. In patients with bundle branch block (BBB), large QRS dispersion of >39 ms was associated with 2.88 times risk (95% CI 1.24–6.71, P = 0.014) of experiencing appropriate therapy than those with QRS dispersion <39 ms. In patients without BBB, reduced maximum T-wave amplitude (≤0.4 mV) were 3.82 times (95% CI 1.63–8.93, P = 0.002) more likely to receive appropriate therapy compared with those with maximum T-wave amplitude >0.4 mV. History of atrial arrhythmia [hazard ratio (HR) = 2.30, 95% CI 1.29–4.12, P = 0.005] and secondary prevention (HR = 2.55, 95% CI 1.14–5.71, P = 0.022) were also predictive of device therapy.

Conclusion
Measurements from standard 12-lead ECG were predictive of appropriate therapy in a heterogeneous ICD population. Incorporation of 12-lead ECG parameters such as these into risk stratification models may improve our ability to select patients for ICD implantation.

Keywords
Implantable cardioverter defibrillator • Electrocardiography • Heart rate variability • T-wave amplitude

Introduction
Implantable cardioverter defibrillators (ICDs) are now the standard of care for patients at high risk of sudden cardiac death. Patients are classified as high risk either because they have had previous episodes of ventricular tachyarrhythmia (secondary prevention),1 or due to an underlying pathophysiology suggestive of high risk (primary prevention), the most common of which is decreased left ventricular ejection fraction (LVEF).2,3 The proportion of patients receiving appropriate therapy from their implanted device has been reported as 29–51% in secondary prevention patients and 15–37% in primary prevention patients in studies with 3–5 years of follow-up.4–6 Because patients never receiving appropriate therapy are still exposed to the risks associated with implantation7 and inappropriate device therapy8 and the health system bears the cost of the implantation and follow-up for these patients,9 it is desirable to improve our ability to select patients who will benefit most from ICDs.

The randomized controlled trials demonstrating benefit of ICDs were largely based around either a previous ventricular tachyarrhythmia or depressed LVEF, and these factors are therefore the basis of most ICD guidelines.10 However, it is possible that there are better methods to determine risk of ventricular tachyarrhythmia than previous events and LV dysfunction. Electrocardiography
What’s new?

- Heart rate variability (HRV) derived from 10 s rhythm strip of standard 12-lead electrocardiography carried a prognostic value of appropriate implantable cardiac defibrillator therapy, where patients with depressed HRV were 2.68 [95% confidence interval (CI) 1.21–5.90, \( P = 0.015 \)] times more likely to receive appropriate therapy.
- QRS dispersion of > 39 ms in patients with BBB was associated with higher risk of receiving appropriate therapy [hazard ratio (HR) = 2.88, 95% CI 1.24–6.71, \( P = 0.014 \)].
- In non-BBB patients, reduced maximum T-wave amplitude was associated with the occurrence of appropriate therapy (hazard ratio = 3.82, 95% CI 1.63–8.93 \( P = 0.002 \)).

(ECG) is a candidate to provide additional information regarding arrhythmic risk. A number of ECG risk markers have been proposed in the literature including microvolt T-wave alternans, QT interval variability, and 24 h heart rate variability (HRV), which all require specific approaches to ECG recording and dedicated computer signal processing.11 The use of a routine 12-lead ECG offers a more ubiquitously accessible form of clinical test where parameters can be measured without the need of complex algorithms, and would therefore be attractive.

We therefore assessed a number of conventional and novel interval, amplitude- and morphology-based measures from routine 10 s 12-lead ECG recordings in a cohort of ICD patients and related these measures to subsequent appropriate device therapy over the follow-up period, in the aim of identifying easy-to-obtain measures from the ECGs that may predict subsequent device therapy in ICD patients.

Methods

Study population

We identified all patients who received their first ICD implantation in New Zealand between March 2007 and March 2010 who were subsequently followed up by the ICD clinic at Wellington Regional Hospital. For each patient a standard 12-lead ECG prior to and closest to the time of implant was selected from medical records for analysis. Patients were excluded if there was no suitable ECG for analysis, or if patients were ventricular paced or in an idioventricular rhythm.

Patient characteristics prior to implant were collected from medical records including demographics, clinical history, implant indication, co-morbidities, and medication. Implant indications were defined as primary prevention if the patient has survived a cardiac arrest or experienced sustained ventricular tachyarrrhythmia. Primary prevention was defined as the absence of cardiac arrest or sustained ventricular tachyarrrhythmia. All implants involved systems with transvenous leads. Programming of devices with ventricular fibrillation (VF) zone occurred in all cases and programming of ventricular tachycardia (VT) zones, antitachycardia pacing (ATP), and monitoring zones was at the discretion of the implanting cardiologist, in which 35 patients (32%) had three-zone programming, 40 patients (37%) had two-zone programming and 33 patients (31%) had one VF zone programmed. Antitachycardia pacing was programmed in the majority of patients (94% of VT zones and 62% of VF zones). This study has been reviewed by the Central Regional Ethics Committee and has been found to conform to the New Zealand standards for observational research.

Follow-up and endpoints

Patients were followed up clinically with device interrogation at a regular interval of 3–6 months. Patients with home monitoring had their transmissions reviewed as they arose. All ATP or defibrillation episodes were reviewed by specialized cardiac technicians and classified as appropriate or inappropriate. If in doubt, they were reviewed independently by an electrophysiologist. The primary endpoint was defined as the first occurrence of appropriate therapy (including ATP/shock) for VT/VF episodes. The last follow-up data were collected in July 2011.

Standard 12-lead ECG analysis

All standard 12-lead ECGs were recorded at a paper speed of 25 mm/s, 10 mm/mV and analysed by a single investigator. Intra-observer variability was tested by blinded repeat measurements on 15 randomly selected ECGs and there was good intraclass correlation coefficient (ICC = 0.93–0.98, \( P < 0.001 \)). Rhythm of the ECG was identified as sinus rhythm, atrial fibrillation (AF), atrial flutter, or atrial-paced rhythm. The presence of left (LBBB) and right bundle branch block (RBBB) were identified according to the American Heart Association (AHA) recommendation for interpretation of ECG.12 Patients with QRS > 120 ms but not meeting the criteria for LBBB or RBBB were classified as non-specific intraventricular block. All ECGs were analysed on paper where measurements were made manually using a caliper to the nearest 1 ms for interval measurements and nearest 0.01 mV for amplitude measurements.

QRS-related measures

QRS duration was measured from the beginning of the Q-wave, or in the absence of Q-wave, the beginning of R-wave to the end of S-wave defined as return to isoelectric line. Maximum and minimum QRS were measured across 12 leads and QRS dispersion was defined as the difference between them. Average QRS was calculated as 0.5 × (maxQRS + minQRS).

The presence of fragmented QRS (fQRS) was examined according to criteria described previously.13,14 For patients without BBB, fQRS-NBBB was defined as various RSR’ patterns with or without Q-wave, including an additional R-wave, notching of the R-wave or notching of the S-wave in two contiguous leads corresponding to a main coronary artery territory (anterior V1-V4, lateral I, aVL, V5-V6, inferior II, III, aVF). For patients with BBB, the criteria of fQRS-BBB were defined as > 2 R-waves or > 2 notches in the R-wave or > 2 notches in the downstroke or upstroke of the S-wave in two contiguous leads in a main coronary artery territory.

QT-related measures

QT interval was measured from the onset of QRS, the same origin used for QRS measurement, to the end of T-wave. T-wave end was defined as returning to the isoelectric line, and in the presence of U-wave the QT interval was measured to the nadir of the curve between the T- and U-waves. Maximum and minimum QT interval across the 12-leads was measured and QT dispersion was defined as the absolute difference. Average QT interval was defined as...
Maximum T-wave amplitude across the 12-leads was measured manually and defined as the maximum of the absolute amplitude from the peak of the T-wave to the isoelectric line regardless of the polarity of the T-wave. In cases of biphasic or bifid T-wave, the peak of the T-wave was used.

**10 s heart rate variability**

From the rhythm strip of either lead II or V1, maximum and minimum RR intervals were measured from R to R peak. Patients in AF, atrial flutter, atrial paced rhythm, second- or third-degree atrio-ventricular (AV) block were excluded for analysis. Atrial and ventricular premature ectopic beats were excluded in the measurement, so only RR interval between sinus beats was measured. Maximum RR difference was calculated as the difference between maximum and minimum RR interval, and normalized to the heart rate by

\[
\text{QTc} = \frac{\text{QT}}{\sqrt{\text{RR}}} \times 100%
\]

\[0.5 \times (\text{max QT} + \text{min QT})\] corrected with the average RR interval using Bazett’s formula

**Statistical analysis**

Categorical variables are expressed as absolute numbers and percentages. Continuous variable are expressed as mean ± standard deviation or median ± interquartile range as appropriate. For categorical variables, difference in the occurrence of appropriate therapy between patient groups was made using Kaplan–Meier survival analysis and log-rank test. Hazard ratio and 95% confidence interval (CI) were derived from univariate Cox proportional hazard model. For continuous variables, comparison between therapy and non-therapy groups was made using independent Student’s t-test for normally distributed variables—QRS intervals, QT intervals, T-wave amplitude, and heart rate. Non-parametric continuous variables—maximum RR difference and 10 s HRV—were compared using Mann–Whitney test. In cases where the continuous variable exhibited significant differences between therapy and non-therapy groups, a receiver operating characteristic (ROC) curve was constructed to obtain the best cut-off point. Patient groups were then determined according to the cut-off point and occurrence of appropriate therapy in each group was examined using Kaplan–Meier curves and log-rank test, with hazard ratio (HRs) and 95% CIs derived using a univariate Cox proportional hazard model. Sub-group analysis in patients with and without BBB was carried out. A P value of <0.05 was considered statistically significant for all tests. All statistical analysis was performed using SPSS 19 (IBM, New York, USA).

**Results**

Over the 3-year implant period 123 patients received new ICD systems, 108 of whom were included in the analysis. The 15 patients excluded either had no qualifying ECG located in their medical records (11), had problems with the quality of the ECG (2), or only had ventricular paced ECG (2). During a mean follow-up of 29 ± 11 months, 47 (44%) patients received appropriate ATP and/or shock therapy from their device. Of this patient group, 17 patients had received ATP only and 30 had received defibrillation ± ATP.

**Clinical characteristics**

Demographic and clinical characteristics of all patients and those who did or did not receive therapy are shown in Table 1. The majority of patients (70%) were implanted with a secondary prevention indication. There was no difference in age, gender, underlying aetiology, and medication between therapy and non-therapy groups. Patients receiving ICDs for secondary prevention were 2.55 (95% CI 1.14–5.71, P = 0.022) times more likely to receive appropriate therapy than patients with primary prevention ICD indications. Patients with a history of atrial arrhythmias prior to implant were 2.30 (95% CI 1.29–4.12, P = 0.005) times more likely to receive appropriate device therapy.

**Electrocardiography measures**

There were 87 patients in sinus rhythm, 18 in AF, 1 in atrial flutter, and 2 patients who were atrial paced. Bundle branch block was present in 47 patients. Electrocardiography measures for all patients are shown in Table 2.

**QRS-related measures**

There was no association between QRS duration and appropriate therapy. QRS dispersion was greater in those who received therapy than those who did not (32 ± 15 vs. 26 ± 14 ms, P = 0.045). In sub-group analysis of patients with no BBB (n = 61) (Table 3), QRS dispersion did not differ with therapy (25 ± 11 vs. 24 ± 12 ms, P = 0.56). However, in patients with BBB (n = 47) (Table 4), the group who received appropriate therapy had greater QRS dispersion than the non-therapy group (39 ± 16 vs. 30 ± 15 ms, P = 0.049). With the optimal cut-off point of 39 ms derived from the ROC analysis, 18 BBB patients had a QRS dispersion >39 ms which was predictive of device therapy compared with BBB patients with QRS dispersion <39 (HR = 2.88, 95% CI 1.24–6.71, P = 0.014) (Figure 1).

A fragmented QRS was observed in 34 patients. QRS fragmentation was noted most frequently in the inferior leads (21 patients), but also in anterior territory in two patients, lateral territory in six patients, and multiple territories in five patients. The presence of fQRS was not associated with appropriate therapy (HR = 1.42, 95% CI 0.78–2.59, P = 0.246).

**QT interval and max T-wave amplitude**

No difference in average QT interval (P = 0.62), average QTc (P = 0.64), or QT dispersion (P = 0.47) was observed between therapy and non-therapy groups. Patients with BBB exhibited significantly larger maximum T-wave amplitude when compared with patients without BBB (0.72 ± 0.37 vs. 0.47 ± 0.27 mV, P < 0.001). In patients without BBB, there was a significant difference in T-wave amplitude between therapy and non-therapy groups (0.36 ± 0.15 vs. 0.55 ± 0.30 mV, P = 0.002). With the best cut-off of 0.4 mV obtained from ROC analysis, non-BBB patients with maximum T-wave amplitude <0.4 mV were 3.82 times (95% CI 1.63–8.93, P = 0.002) more likely to receive device therapy than those with maximum T-wave amplitude ≥0.4 mV (Figure 2). In patients with BBB, no difference
between therapy and non-therapy groups was observed (0.76 ± 0.44 vs. 0.68 ± 0.30 mV, \( P = 0.43 \)).

### 10 s heart rate variability

The average heart rate of our study population was 63 ± 13 b.p.m. with no difference observed between patients who received appropriate therapy and those who did not (\( P = 0.82 \)). After exclusion of patients in AF, atrial flutter, atrial pacing, and second or third AV block, HRV was examined in 86 patients, as shown in Table 5. Premature ventricular complexes were present in 13 patients (ranging from 1 to 5 ectopic complexes) and premature atrial complexes were present in two patients. The affected ectopic coupling interval and compensatory pause were not included in the calculation of HRV. The median maximum RR difference was 48 (22–96 ms). By normalizing maximum RR difference to the heart rate, patients with therapy exhibited reduced 10 s HRV compared with those with no therapy received [3.6 (1.8–6.1) vs. 6.6 (3.0–10.0)%, \( P = 0.039 \)]. At a cut-off of 6.5% obtained from the ROC curve, patients with depressed HRV (≤6.5%) were 2.68 (95% CI 1.21–5.90, \( P = 0.015 \)) times more likely to receive therapy than patients with HRV > 6.5% (Figure 3).

### Discussion

From a routine 12-lead ECG prior to implantation of an ICD we identified 10 s HRV, QRS dispersion, and maximum T-wave amplitude to be associated with an increased risk of appropriate device therapy. In contrast, previously suggested measures including QRS duration, QT duration, QT dispersion, and IQRS were not associated with an increased risk of therapy in our population of ICD patients.

We observed that depressed HRV measured from the 10 s rhythm strip was associated with higher risk of experiencing appropriate therapy. Receiver operating characteristic curve analysis indicated a threshold value of 6.5% maximum RR difference, and using this value there was a 2.68 (95% CI 1.21–5.90) relative risk associated with lower HRV. Heart rate variability is a widely used non-invasive measure of the autonomic tone, in which increased sympathetic and decreased parasympathetic activity has been implicated in arrhythmogenesis. \(^{15}\) Decreased levels of HRV obtained from 5 min to 24 h recordings have been associated with adverse outcome in a range of different clinical settings. \(^{16}\) Battipaglia et al.\(^{17}\) observed that decreased HRV was associated with the occurrence of arrhythmic events in ICD patients, but other groups have not observed this relationship. \(^{18,19}\) Heart rate variability derived from a 10 s measurement has not been regarded as a standard measurement. The presence of ectopic beats within the 10 s recording in 15 patients may also have influenced this measurement. However, 10 s HRV is correlated with cardiac parasympathetic activity derived from 5 min HRV assessments, \(^{20,21}\) and therefore is a marker of cardiac vagal tone. There is some evidence that decreased 10 s HRV is associated with increased mortality. \(^{22,23}\) In this context, our observation that decreased 10 s HRV was associated with an increased risk of arrhythmic events is

### Table 1  Patient demographics and clinical characteristics

<table>
<thead>
<tr>
<th></th>
<th>All (n = 108)</th>
<th>Therapy (n = 47)</th>
<th>No therapy (n = 61)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>81 (75)</td>
<td>38 (81)</td>
<td>43 (71)</td>
<td>0.31</td>
</tr>
<tr>
<td>Age (years)</td>
<td>58 ± 13</td>
<td>60 ± 13</td>
<td>57 ± 14</td>
<td>0.28</td>
</tr>
<tr>
<td>Clinical history</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ischaemic heart disease</td>
<td>60 (56)</td>
<td>29 (62)</td>
<td>31 (51)</td>
<td>0.22</td>
</tr>
<tr>
<td>Non-ischaemic DCM</td>
<td>25 (23)</td>
<td>11 (23)</td>
<td>14 (23)</td>
<td>0.79</td>
</tr>
<tr>
<td>HCM</td>
<td>9 (8)</td>
<td>2 (4)</td>
<td>7 (11)</td>
<td>0.20</td>
</tr>
<tr>
<td>Other pathology(^a)</td>
<td>14 (13)</td>
<td>5 (11)</td>
<td>9 (15)</td>
<td>0.54</td>
</tr>
<tr>
<td>LVEF (%)</td>
<td>38 ± 15.8</td>
<td>35 ± 14.2</td>
<td>40 ± 16.6</td>
<td>0.08</td>
</tr>
<tr>
<td>Heart failure</td>
<td>65 (60)</td>
<td>32 (68)</td>
<td>33 (54)</td>
<td>0.12</td>
</tr>
<tr>
<td>History of atrial arrhythmias</td>
<td>42 (39)</td>
<td>24 (51)</td>
<td>18 (30)</td>
<td>0.005</td>
</tr>
<tr>
<td>(\beta)-Blocker</td>
<td>93 (86)</td>
<td>40 (85)</td>
<td>53 (87)</td>
<td>0.86</td>
</tr>
<tr>
<td>ACEI/ARBs</td>
<td>82 (76)</td>
<td>38 (81)</td>
<td>44 (72)</td>
<td>0.18</td>
</tr>
<tr>
<td>Diuretics</td>
<td>52 (48)</td>
<td>25 (53)</td>
<td>27 (44)</td>
<td>0.17</td>
</tr>
<tr>
<td>Class III anti-arrhythmics</td>
<td>32 (30)</td>
<td>17 (36)</td>
<td>15 (25)</td>
<td>0.19</td>
</tr>
<tr>
<td>Implant information</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primary prevention</td>
<td>32 (30)</td>
<td>7 (15)</td>
<td>25 (41)</td>
<td>0.022</td>
</tr>
<tr>
<td>Secondary prevention</td>
<td>76 (70)</td>
<td>40 (85)</td>
<td>36 (59)</td>
<td></td>
</tr>
<tr>
<td>Single-chamber ICD</td>
<td>63 (58)</td>
<td>30 (64)</td>
<td>33 (54)</td>
<td>0.50</td>
</tr>
<tr>
<td>Dual-chamber ICD</td>
<td>30 (28)</td>
<td>12 (25)</td>
<td>18 (30)</td>
<td>0.81</td>
</tr>
<tr>
<td>CRT-D</td>
<td>15 (14)</td>
<td>5 (11)</td>
<td>10 (16)</td>
<td>0.52</td>
</tr>
</tbody>
</table>

Data are presented as \( n \) (%) or mean ± SD.

ACEI, angiotensin-converting enzyme inhibitor; ARB, aldosterone receptor antagonist; CRT-D, cardiac resynchronisation therapy defibrillator; DCM, dilated cardiomyopathy; HCM, hypertrophic cardiomyopathy; ICD, implantable cardioverter defibrillator; IQR, interquartile range; LVEF, left ventricular ejection fraction.

\(^a\)Others include arrhythmogenic right ventricular cardiomyopathy, Brugada syndrome, long-QT syndrome, idiopathic ventricular fibrillation, and primary valvular disease.
consistent with the view that higher levels of cardiac vagal tone is associated with a lower risk of arrhythmia.

In our study, we did not observe an association between prolonged QRS duration and arrhythmic risk, a finding that is consistent with those of a number of other studies. QRS dispersion, the inter-lead difference in QRS duration, has been hypothesised as a measure of conduction heterogeneity. In the current study, QRS dispersion was found to be significantly higher in patients with BBB than patients without BBB, likely to reflect the greater depolarization heterogeneity in BBB patients. In the subgroup of patients with BBB, greater QRS dispersion was associated with a 2.88 relative risk of appropriate therapy. QRS dispersion has not been previously investigated in relation to ventricular arrhythmic events in ICD patients. Other studies have reported that QRS dispersion is a risk marker for arrhythmic death in arrhythmogenic right ventricular cardiomyopathy and heart failure patients, although not in post-myocardial infarction patients. Kearney et al. argued that QRS dispersion was simply a reflection of maximum QRS duration and demonstrated QRS duration to carry prognostic value as well, although not to the same extent. In our study, a positive correlation between QRS dispersion and maximum QRS duration was observed, but no prognostic value of maximum QRS duration was found. Therefore, it is possible that QRS dispersion is a better measure of inhomogeneous electrical depolarization and regional conduction delays than QRS duration. The observed association of increased QRS dispersion with increased risk of appropriate therapy in BBB patients may be a reflection of increased depolarization heterogeneity predisposing to increased arrhythmic risk. With the increasing use of cardiac

### Table 2 Electrocardiography parameters in all patients

<table>
<thead>
<tr>
<th></th>
<th>All (n = 108)</th>
<th>Therapy (n = 47)</th>
<th>No therapy (n = 61)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>QRS-based measures</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average QRS (ms)</td>
<td>118 ± 31</td>
<td>119 ± 32</td>
<td>118 ± 30</td>
<td>0.87</td>
</tr>
<tr>
<td>QRS dispersion (ms)</td>
<td>29 ± 14</td>
<td>32 ± 15</td>
<td>26 ± 14</td>
<td>0.045</td>
</tr>
<tr>
<td>fQRS</td>
<td>34 (32)</td>
<td>17 (36)</td>
<td>17 (28)</td>
<td>0.24</td>
</tr>
<tr>
<td><strong>QT based measures</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average QT (ms)</td>
<td>432 ± 51</td>
<td>435 ± 48</td>
<td>430 ± 54</td>
<td>0.62</td>
</tr>
<tr>
<td>Average QTc (ms)</td>
<td>437 ± 48</td>
<td>440 ± 45</td>
<td>435 ± 50</td>
<td>0.64</td>
</tr>
<tr>
<td>QT dispersion (ms)</td>
<td>63 ± 34</td>
<td>66 ± 34</td>
<td>61 ± 35</td>
<td>0.47</td>
</tr>
<tr>
<td>Maximum T amp (mV)</td>
<td>0.58 ± 0.34</td>
<td>0.55 ± 0.38</td>
<td>0.60 ± 0.30</td>
<td>0.41</td>
</tr>
<tr>
<td>Average heart rate</td>
<td>63 ± 13</td>
<td>62 ± 12</td>
<td>63 ± 14</td>
<td>0.82</td>
</tr>
</tbody>
</table>

Data are presented as n (%) or mean ± SD. amp, amplitude; fQRS, fragmented QRS.

### Table 3 Sub-group patients with no bundle branch block

<table>
<thead>
<tr>
<th></th>
<th>All (n = 61)</th>
<th>Therapy (n = 25)</th>
<th>No therapy (n = 36)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average QRS (ms)</td>
<td>96 ± 13</td>
<td>95 ± 12</td>
<td>97 ± 14</td>
<td>0.42</td>
</tr>
<tr>
<td>QRS dispersion (ms)</td>
<td>24 ± 11</td>
<td>25 ± 11</td>
<td>23 ± 12</td>
<td>0.56</td>
</tr>
<tr>
<td>Maximum T-wave amplitude (mV)</td>
<td>0.47 ± 0.27</td>
<td>0.36 ± 0.15</td>
<td>0.55 ± 0.30</td>
<td>0.002</td>
</tr>
</tbody>
</table>

Data are presented as mean ± SD.

### Table 4 Sub-group of patients with bundle branch block

<table>
<thead>
<tr>
<th></th>
<th>All (n = 47)</th>
<th>Therapy (n = 22)</th>
<th>No therapy (n = 25)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average QRS (ms)</td>
<td>146 ± 23</td>
<td>146 ± 25</td>
<td>147 ± 22</td>
<td>0.89</td>
</tr>
<tr>
<td>QRS dispersion (ms)</td>
<td>35 ± 16</td>
<td>39 ± 16</td>
<td>30 ± 15</td>
<td>0.049</td>
</tr>
<tr>
<td>Maximum T-wave amplitude (mV)</td>
<td>0.72 ± 0.37</td>
<td>0.76 ± 0.44</td>
<td>0.68 ± 0.30</td>
<td>0.43</td>
</tr>
</tbody>
</table>

Data are presented as mean ± SD.

### Figure 1 Kaplan–Meier curve of appropriate therapy in bundle branch block patients with QRS dispersion <39 and >39 ms.
resynchronization therapy in BBB patients, the link between QRS dispersion and arrhythmic events may have implications in decision making between cardiac resynchronisation therapy pacemaker and cardiac resynchronisation therapy defibrillator implantation and the predictive value of QRS dispersion needs to be confirmed by larger studies.

We observed that in patients without BBB, reduced maximum T-wave amplitude was a significant predictor of the occurrence of ventricular arrhythmias with a relative risk of 3.82 associated with maximum T-wave amplitude less than 0.4 mV. While there is uncertainty of the underlying meaning of T-wave amplitude, previous studies have demonstrated that maximum spatial T amplitude was reduced in hypertensive patients compared to normal controls, and even more reduced in hypertensive patients with left ventricular hypertrophy. In post-MI, T-wave amplitude has also been shown to be reduced. It is therefore possible that decreased T-wave amplitude is a pathological sign, but further work is required to understand the basis and significance of this. The reason maximum T-wave amplitude only had predictive value in non-BBB patients is unclear. Different mechanisms such as depolarization derangement seen in BBB may contribute to different T-wave morphology and influence its predictive value.

A number of other ECG-derived parameters have previously been proposed to confer risk of sudden cardiac death, or arrhythmic events in ICD patients. These include indices linked to abnormalities in depolarization of the ventricle, such as fQRS, and abnormalities of repolarization such as QT dispersion. None of these parameters were associated with a significant increased risk of appropriate therapy in our study population.

Limitations

Our study was retrospective in nature therefore the conditions under which the ECG was recorded was not standardized. The study population was relatively small, as the number of devices implanted and followed up in our centre is low. We are therefore unable to carry out multivariate analysis, and also unable to exclude the possibility of some of the negative findings in our study to be due to a lack of statistical power. Our study population has a high proportion of secondary prevention patients (70%). Further larger studies in a primary prevention population are needed to prove the utility of these ECG parameters. Our study population was a heterogeneous group of patients and the application risk markers may differ between patients of different aetiology, but this does not conflict with the aim of our study of ECG markers of arrhythmic risk.

Conclusion

A routine 12-lead ECG is a valuable clinical diagnostic tool that is universally accessible with low burden of analysis. We have identified features of the ECG that are associated with significant risk of arrhythmic events in a heterogeneous population of patients receiving ICDs. Further investigation of how ECG-based...
measurements may be incorporated into clinical decision making in potential ICD candidates is required.

**Conflict of interest:** none declared.

**References**


