QTc Interval as a Guide to Select Those Patients With Congestive Heart Failure and Reduced Left Ventricular Systolic Function Who Will Benefit From Antiarrhythmic Treatment With Dofetilide

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Background—A prolonged QTc interval is considered a contraindication for class III antiarrhythmic drugs, but the influence of a normal or a slightly increased baseline QTc interval on the risk or benefit of treatment with a class III antiarrhythmic drug is not sufficiently clarified.

Methods and Results—This prospectively defined substudy included 703 patients enrolled in the Danish Investigations of Arrhythmia and Mortality on Dofetilide-Congestive Heart Failure (DIAMOND-CHF) study. Patients included had moderate to severe CHF and reduced left ventricular systolic function. Baseline QTc interval was measured before randomization to either dofetilide, a new class III antiarrhythmic drug, or placebo. During a median follow-up of 18 months (minimum 1 year), 285 patients (41%) died. Baseline QTc interval had no prognostic value on survival in placebo-treated patients. In dofetilide-treated patients, a baseline QTc interval ≤429 ms was associated with a significant risk reduction (risk ratio 0.4, 95% CI 0.3 to 0.8). With increasing QTc interval, the risk increased gradually, and for QTc interval >479 ms, risk ratio was 1.3 (0.8 to 1.9).

Conclusions—A baseline QTc interval within normal limits is associated with a marked reduction of mortality in patients with CHF and left ventricular systolic dysfunction treated with dofetilide. This is a potentially important indication of which patients with CHF might benefit from prophylactic treatment with an antiarrhythmic drug. (Circulation. 2001; 103:1422-1427.)

Key Words: heart failure ■ prognosis ■ antiarrhythmia agents

Within the past 2 decades, characterization of the overall ventricular repolarization status by the QTc interval has led to an extensive search for the use of the QTc interval as a prognostic marker of ventricular tachyarrhythmias and death. Vaughan Williams class IA or class III antiarrhythmic drugs, such as quinidine and sotalol, are known to prolong myocardial repolarization. This may either provide a protective effect against arrhythmias or lead to an increased occurrence of QTc interval–related arrhythmias, in particular torsade de pointes ventricular tachycardia (TdP VT).1 Because it is not possible to predict which effect will predominate, common practice has been to avoid these drugs in patients with excessive baseline QTc intervals, although a uniform “cutoff point” for when QTc interval contraindicates repolarization-prolonging antiarrhythmic drugs has not been established.

Dofetilide, a new “pure” class III drug, increases repolarization time by blocking the rapid component of the delayed rectifier of the potassium current2 and may therefore have the potential of inducing TdP VT and death. The importance of baseline QTc interval for patients receiving dofetilide has not yet been established.

For patients with congestive heart failure (CHF), interest in QT parameters started relatively late. To date, prognostic survival studies for QTc interval for patients with CHF are few, although these patients are known to have a high mortality, including a high risk of sudden cardiac death.3

With this in mind, we performed a prospective substudy of the Danish Investigations of Arrhythmia and Mortality on Dofetilide-CHF (DIAMOND-CHF) study population to investigate the prognostic value of QTc interval in CHF patients receiving traditional treatment, as well as in patients receiving dofetilide in addition to traditional treatment.
screening procedure included echocardiography, and to be randomiz-ized, the patients were required to have left ventricular systolic dysfunction with a wall motion index (WMI) $\leq 1.2$, corresponding to an ejection fraction $\leq 35$. Of the 5812 patient screenings, 1518 patients were enrolled.

In accordance with the main study protocol, a 12-lead baseline ECG was available locally in all 1518 patients enrolled. Our predefined substudy protocol required that an additional predose baseline ECG was sent to us for central evaluation, and this was achieved in 1319 patients. All definitions were made before QT data were compared with survival data.

Patients with an acute myocardial infarction within 7 days, a locally measured baseline QTc interval $>460$ ms (500 ms in patients with bundle-branch block [BBB]), severe noncardiac disease, severe electrolyte abnormality, or severe renal dysfunction and patients receiving a class I or class III antiarrhythmic drug were excluded. Patients unwilling to participate or incapable of participation were also excluded.

Written informed consent was obtained. The study was approved by the Danish Board of Health and the involved ethics committees.

**QTc Interval**

QT interval was measured in 630 ECGs (48%) of the 1319 baseline ECGs recorded. Reasons for not measuring QT interval were atrial fibrillation ($n=371$), $<9$ readable leads ($n=259$), poor recording quality ($n=11$), pacemaker rhythm ($n=45$), and bigeminy ($n=3$). Another 73 ECGs of placebo-treated patients without baseline ECG but with a measurable ECG taken within 6 days after randomization were included in the study, leading to 703 patients with a measurable ECG.

Two consecutive QT intervals were measured in all 12 leads of a standard ECG by 1 of 2 experienced observers by a computerized digitizer tablet (Cherry, Mk III Graphic tablet, resolution 0.1 mm). The QT interval was measured from the beginning of the QRS complex to the visual return of the T wave to the isoelectric line and was heart rate–corrected with the Bazett formula, QTc = QT/√RR. This method is similar to several other relevant studies. When the QTc interval was calculated from all QTc intervals measured.

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**Methods**

**Patients**

The Diamond-CHF study was a double-blind, placebo-controlled, randomized study prospectively evaluating the effect of dofetilide on mortality for patients with CHF. The study was conducted in 34 hospitals in Denmark from 1993 to 1996. Patients were screened consecutively if they fulfilled the following criteria: age $\geq 18$ years and hospitalization with CHF of all causes with an NYHA functional class III or IV within the last month before randomization. The

**Follow-Up**

Patients were followed up for a minimum of 1 year (median follow-up 18 months). No patient was lost to follow-up.

**End Points**

End points were mortality end points from the main DIAMOND-CHF study. The primary end point was all-cause mortality, and secondary end points included death from cardiac causes as evalu-
ated by members of an event committee of the main study. All available data in connection with an end point were reviewed on a blinded basis, and the end point was subsequently classified according to the CAPS criteria8 (with the exception that successful resuscitation of cardiac arrest was not considered as death).

Statistical Analysis
Continuous data are reported as median and 5%/95% percentiles. Comparisons between groups were made by χ2 test for discrete data and by nonparametric ANOVA (Kruskal-Wallis test) for continuous data.

Survival analysis included Kaplan-Meier curves and univariate and multivariate Cox proportional-hazard models. Variables considered for multivariate analysis were QTc interval; placebo/dofetilide; sex; age; heart rate; smoking status; history of diabetes, ischemic heart disease, or hypertension; use of β-blockers, calcium antagonists, digoxin, or diuretics; BBB; WMI; NYHA class; and serum potassium and creatinine. Only variables with independent prognostic importance were retained in the final model. Assumptions of the Cox models (proportional hazards, interactions, and linearity for the risk estimates of a continuous variable) were tested. QTc interval and QTc prolongation between baseline and day 2 to 6 were tested both as continuous variables and as quartiles (the latter analysis being used for the final model). Results from the Cox analysis are expressed as relative risk (RR) with a 95% CI.

The Statistical Analysis System version 6.12 (SAS Institute, Inc.) was used for all statistical analysis. Analysis was made on an intention-to-treat basis. A test was considered statistically significant at a corresponding value of P≤0.05.

Results

Baseline Characteristics and QTc Interval
Table 1 shows baseline characteristics in the placebo group and in the dofetilide group. QTc intervals were longer for patients with BBB (QRS ≥120 ms) in both groups (placebo group, 473 [416 to 532] versus 442 [394 to 494] ms; dofetilide group, 475 [426 to 515] versus 443 [390 to 500] ms). For patients with ischemic heart disease and for patients treated with digoxin, there was a tendency toward shorter QTc intervals. There was no difference in QTc interval between groups with or without treatment with β-blockers, diuretics, or ACE inhibitors.

End Points and QTc Interval
During follow-up, 168 placebo-treated patients (42%) and 117 dofetilide-treated patients (39%) died. Of these, 125 (31%) and 94 (31%) patients died of cardiac causes, respec-

![Figure 1. Cumulative all-cause mortality as estimated by Kaplan-Meier method. Baseline QTc interval dichotomized from 2 lower and 2 upper quartiles, with 454 ms being median.](image)

Univariate Survival Analysis
All-cause mortality curves for placebo- and dofetilide-treated patients are shown in Figure 1. Similar results were also seen for cardiac death (log-rank test, placebo group, P>0.7; log-rank test, dofetilide group, P<0.02).

Considering only patients from the 2 lower QTc interval quartiles, patients receiving dofetilide had an all-cause mortality risk reduction of 40% compared with the placebo group (risk ratio 0.6, 95% CI 0.4 to 0.9, P<0.02). For the 2 upper QTc interval quartiles, dofetilide demonstrated a trend for a 20% increased mortality risk compared with placebo (1.2, 0.9 to 1.7, P>0.16).

Multivariate Survival Analysis
A considerable difference in the effect of QTc interval on mortality between placebo- and dofetilide-treated patients was confirmed in the test for interaction (P=0.0004), making it necessary to consider placebo- and dofetilide-treated patients separately.

The variable for QTc interval was then divided into quartiles in multivariate analysis to substantiate the difference between placebo- and dofetilide-treated patients, with the lowest quartile for placebo-treated patients serving as reference (with a default risk ratio of 1) for both treatment groups.

Table 3 and Figure 2 show the results from multivariate Cox analysis for all-cause mortality. A similar analysis on maximum QTc interval revealed a similar but weaker tendency on all-cause mortality.

BBB did not hold multivariate predictive value for all-cause mortality in either of the 2 treatment groups (placebo, P>0.7; dofetilide, P>0.3). In the dofetilide group, QTc interval contained greater predictive value for patients without BBB than those with BBB (test for interaction, P=0.03). No such tendency was seen in the placebo group.

To test whether the prognostic value of QTc interval was carried solely by the effect of heart rate included in the QTc interval, analysis was repeated after QTc interval was replaced with heart rate. No difference in prognostic value was seen between placebo- and dofetilide-treated patients (test for interaction, P=0.27). Also, in a model in which the uncorrected QT interval and heart rate were included as separate
variables, QT interval contained independent prognostic value as long as heart rate was retained in the analysis.

In 454 of the 703 patients, QTc interval was available from an ECG taken within 2 to 6 days after randomization. For dofetilide-treated patients, QTc interval increment from baseline to day 2 to 6 was larger for the lower quartiles (median differences [in ms], lower to upper quartiles: 32 [26–4/94], 33 [1/82], 23 [22–29/79], 15 [23–32/62], P = 0.0002). Multivariate survival analysis on postrandomization ECGs showed the same tendency (but weaker) for the effect of QTc interval quartiles on mortality in the dofetilide group as for analysis made on baseline ECGs. Interaction analysis revealed no relationship on all-cause mortality between baseline QTc interval and changes in QTc intervals from baseline to day 2 to 6 (P = 0.17).

For patients who suffered a cardiac death, a weaker but similar tendency in the prognostic value of the QTc interval was seen as for patients who died from all-cause mortality (placebo: no prognostic value; dofetilide: RR 0.5, 0.9, 1.2, 1.3; probability value 0.04, 0.78, 0.58, 0.27).

In the dofetilide-treated patients, the prognostic importance of the QTc interval was not dependent on stratification by sex (P = 0.27, with probability value referring to test for interaction between QTc interval and stratum), age (<60 years, ≥60 years) (P = 0.62), WMI (<0.8, 0.8 to 1.2) (P = 0.96), smoking status (P = 0.40), serum creatinine (≥130 mmol/L, >130 mmol/L) (P = 0.98), NYHA class (I and II, III and IV) (P = 0.57), diabetes (P = 0.47), ischemic heart disease (P = 0.78), arterial hypertension (P = 0.16), β-blocker (P = 0.48), or digoxin (P = 0.94).

Analysis on the locally measured baseline QTc interval (single-lead measurements, preferably in lead II, by an investigator at the local site just before randomization) on all-cause mortality for all patients randomized revealed the same trend as for our measurements, although this did not reach statistical significance (placebo: no prognostic value; dofetilide: RR 0.8, 0.9, 1.00, 1.03; probability value 0.10, 0.53, 0.98, 0.83).

The above-mentioned results of our study were tested excluding the 73 placebo-treated patients with postrandomization ECGs only. This did not change the results.

Discussion

This study suggests that dofetilide reduces mortality in patients with CHF and reduced left ventricular systolic function, provided that QTc interval before treatment is short. For those patients within the highest quartile of baseline QTc interval, the risk of death is increased compared with placebo, albeit not significantly. The median QTc in our study was 454 ms, close to the upper normal limit of 440 ms used in many studies.

Our data do not explain the findings, but a likely explanation may lie in the balance between the protective effect of prolonging the refractory period with class III antiarrhythmic
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larger prospective multivariate survival study on QTc interval in CHF is likewise poorly described in the literature. The only article. The prognostic value of QTc interval in patients with intervals in our study.

was not highly dependent on baseline QTc interval and because the risk of mortality caused by these changes was not dependent on baseline QTc interval.

The results of this study were obtained with QT intervals corrected for heart rate with the Bazett formula and as a mean of all leads in which QT could be measured. We performed additional analyses that demonstrated the same results with uncorrected QT intervals, provided that the proportional-hazard model included adjustment for heart rate. The results are therefore driven primarily by the QT interval corrected for heart rate.

A trend on mortality for QTc intervals similar to that seen in our study was also seen for the whole DIAMOND-CHF study, in which QTc intervals were measured in single leads by many investigators. Our measurement of the mean QTc interval from all available leads removes the bias of investigator preference in selection of leads and perhaps also the effect of outliers. It is therefore not surprising that a more precise result is obtained in this much smaller study. The maximal QTc interval has a theoretical advantage, because the interval should describe the maximal repolarization length, but the maximal QTc interval also has the disadvantage of being biased by measurement errors. It is therefore not surprising that similar but insignificant trends were obtained with maximal QTc intervals compared with mean QTc intervals in our study.

No other study has addressed the issue reported in this article. The prognostic value of QTc interval in patients with CHF is likewise poorly described in the literature. The only larger prospective multivariate survival study on QTc interval for patients with CHF so far was made by Brooksby et al. During a mean (SD) follow-up of 471 (168) days, 71 (14%) of the 554 patients died. Maximum QTc interval was found to hold no multivariate prognostic value on all-cause mortality (RR and CI not supplied). In 603 post–myocardial infarction patients with CHF, Spargias et al found QTc interval in nonsurvivors to be longer than in survivors (nonsurvivors, mean [SD] QTc interval 447.2 [40.2]; survivors, 431.8 [33.4], P<0.001), but multivariate survival analysis was not performed on QTc interval. Small-scale studies on differences in QTc interval for survivors and nonsurvivors in CHF patients are variably negative and positive.

Baseline QTc interval prolongation is known to be a cause for caution when prescribing class Ia or class III antiarrhythmic drugs, because they may induce TdP VT. Our study raises the intriguing question of whether other, mostly neutral or negative prognostic studies regarding prophylactic use of class III antiarrhythmic drugs in high-risk patients could have had a different outcome had the patients been stratified according to baseline QTc intervals. Perhaps an insufficient risk stratification of the patients rather than lack of efficacy of the drugs caused the results of these studies. In this context, it is important to note that investigator measurement in a single lead only indicated a trend, compared with the much more convincing result of a measurement based on all available leads. Therefore, future studies and reevaluation of previous studies should attempt to use measurements based on multiple leads.

Study Limitations

The most important limitation is that the data come from a substudy of a randomized clinical trial with a neutral outcome. Therefore, the results must be interpreted with caution and need to be confirmed in other studies as well as in a prospective clinical trial before they can be considered fully valid.

As a result of the combined entry criteria of NYHA class III/IV and low left ventricular systolic function, this study was performed on high-risk CHF patients. This was before the use of β-blockers and spironolactone was implemented in patients with CHF. Therefore, our results cannot be directly applied to all CHF patients treated with present treatment strategies.

One of the exclusion criteria for the DIAMOND-CHF study was a QTc (single lead) >460 ms (>500 ms in case of BBB). This may have excluded some patients with repolarization abnormalities from our study.

Conclusions

In dofetilide-treated patients with moderate to severe CHF and reduced left ventricular systolic function, a short baseline QTc interval is associated with reduced mortality. With increasing baseline QTc interval, the risk of death systematically increases. Our study is the first to point to a possible risk stratification strategy from a standard ECG in high-risk CHF patients with respect to subsequent treatment with a class III antiarrhythmic drug.

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