Severe iatrogenic bradycardia related to the combined use of beta-blocking agents and sodium channel blockers

Purpose: Drug-induced bradycardia is common during antiarrhythmic therapy; the major culprits are beta-blockers. However, whether other antiarrhythmic drugs are also a significant cause of this, alone or in combination with beta-blockers, is not well known.

Methods: We retrospectively investigated the records of all patients hospitalized at our institution for drug-related bradycardia from the years 2004 to 2012. Patients with cardiac disease and electrolytic or hormonal abnormalities that could cause bradyarrhythmias were excluded.

Results: Eight patients were identified (mean age, 79±5 years; range, 71–85 years; 6 women). Three patients were taking only beta-blockers (hereafter referred to as the BB group), while five patients were on both beta-blockers and Na channel blockers (hereafter referred to as the BB + Na group). Heart rates ranged from 20–49 beats/minute on arrival. The initial electrocardiogram showed sinus bradycardia (n=6) or sinus arrest with escape beats (n=2). QRS duration was 80–100 ms. The clinical presentation of the BB + Na group was considerably worse than that of the BB group, and included cardiogenic shock and heart failure. Four of the BB + Na patients had been on their medications for over 300 days. The BB group recovered solely with drug discontinuation, while 4 of the 5 patients in the BB + Na group needed additional treatments, such as intravenous administration of atropine or adrenergic agonist and temporary pacing. Bradycardia did not recur during follow-up (median, 687 days).

Conclusion: Although wide QRS ventricular tachyarrhythmia is a better known proarrhythmic effect of Na channel blockers, life-threatening bradycardia may also occur in combination with beta-blockers in the elderly, even months after the start of medication, and at plasma concentrations that do not prolong QRS width.

Keywords: proarrhythmia, elderly, QRS duration

Introduction

Drug-induced bradycardia is an important and common but poorly characterized clinical problem. Clinically, severe bradycardia can be induced during therapy with beta-adrenergic-blockers (beta-blockers), non-dihydropyridine calcium channel antagonists, and though rare, with any of the other classes of antiarrhythmic drugs.1–8

Beta-blockers are the most common culprits in causing bradycardia, interfering with slow action potential generation and atrioventricular conduction. They target the sympathetic nervous system and have negative chronotropic and inotropic effects. In chronic heart failure, beta-blocker therapy protects the heart against cardiotoxic over-stimulation by the catecholamines, improving left ventricular function and performance. Such therapy also improves survival and reduces risk of arrhythmias (sudden cardiac death). On the other hand, beta-blockers are contraindicated in acute heart failure...
because they decrease cardiac output acutely. Their negative chronotropic effects could slow down the heart rhythm to an unexpected degree. The purpose of this study was to examine drugs that cause marked bradycardia.

**Methods**

**Study subjects**

In this retrospective study, we reviewed all patients that visited the emergency department of our hospital, the Tokyo Medical and Dental University, or were hospitalized between January 2004 and August 2012 with a diagnosis of emergent bradycardia associated with drug side effects. Patients were excluded if their bradycardia was attributable to cardiac disease, eg, acute myocardial infarction, vasovagal syncope, cardiac myopathy, myocarditis, or failure of a previously implanted pacemaker device. We also excluded patients who had electrolyte imbalances or hormonal abnormalities. The cause-and-effect relationship between medication use and bradycardia was determined from the response to drug withdrawal. This study was approved by our institutional ethics committee.

**Follow-up**

Medications suspected of being the cause of bradycardia were discontinued in all subjects soon after admission. Whether or not clinically significant and symptomatic bradycardia recurred after discharge was assessed during the follow-up period. Because of the small number of patients, we did not conduct statistical analyses. All values are expressed as mean ± standard deviation.

**Results**

Eight patients were found who fulfilled our criteria for inclusion. Baseline characteristics of the study population are shown in Table 1. The mean age was 78.5 ± 10 years (range, 71–85), and six patients were women. With regard to antiarrhythmic medications, three patients were taking beta-blockers only (in the BB group), while five patients were on both beta-blockers and Na channel blockers (in the BB + Na group). The beta-blockers were carvedilol (n=3), metoprolol (n=2), betaxolol, bisoprolol, and carteolol (n=1 each). The Na channel blockers were pilsicainide, which is a pure Na channel blocker (n=2), and disopyramide, flecainide, mexiletine, and cibenzoline (n=1 each). One patient was also on a calcium channel antagonist, but it was a dihydropyridine that generally had no chronotropic effects.

The duration that the patients had been on these medications before their bradycardic event ranged from 6 hours to 6 years before their bradycardic event ranged from 6 hours to 6 years.

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Bradycardia is a possible side effect of all classes of

(at > median, 332.5 days). The indications for treatment with these
drugs were tachyarrhythmia (n=7), hypertension (n=5), and
stable angina pectoris (n=1).

The most common presenting symptom was syncope
(Table 2). The patients’ heart rates ranged from 20–49 beats/minute
on arrival. The initial electrocardiogram (ECG) showed sinus bradycardia in six patients and sinus arrest
with escape beats in two patients (Figures 1–4). The mean
QRS duration was 91.5±8.2 ms (range, 80–100 ms). Two-dimensional echocardiography was performed in all patients
and showed a mean left ventricular ejection fraction of 72±9% (range, 60–84%). The clinical presentation of the BB + Na
group was considerably worse than that of the BB group, and
included three patients with cardiogenic shock and one patient
with heart failure. All patients in the BB group presented with
syncope and recovered solely with drug discontinuation. In
contrast, in the BB + Na group, only one patient recovered
solely with drug discontinuation, and the remaining four
patients needed supportive medical treatment that included
intravenous administration of atropine or adrenergic agonist;
two of these patients required temporary pacing as well. Of
these two patients, one also required mechanical ventilation
and needed transfer to the intensive care unit (Patient 1). The
duration for full recovery after medication withdrawal was
longer in the BB + Na group (11.3±8.6 hours in the BB +
Na group vs 5.2±2.5 hours in the BB group).

Serum concentration of the Na channel blockers was mea-
sured in three patients. The serum concentration exceeded the
therapeutic range in one of those three patients. The median
follow-up duration was 687 days (range, 43–2,475 days).
Holter monitoring was performed in two patients during the
follow-up period, resulting in no remarkable findings, includ-
ing bradycardia. None of the patients developed bradycardia
again during the follow-up period. Therefore, no permanent
pacemaker implantation was performed.

At our hospital, beta-blockers were prescribed to
2,964 patients and Na channel blockers to 946 patients dur-
ing the past year. Of these, 415 patients took both. In this
study, we found eight patients demonstrating life-threatening
drug-induced bradycardia over 8 years. According to a rough
estimate, the annual incidence of severe drug-induced bra-
dycardia would be 0.0015% in patients taking beta-blockers
alone and 0.15% in those taking the combination of Na
channel- and beta-blockers.

We describe in more detail patient 1, who had the worst
clinical presentations of the patients in our study. Patient 1
was an 80-year-old woman, who was referred to our hospital
for chest discomfort lasting 5 hours. She had been diagnosed
with paroxysmal atrial fibrillation (AF) and hypertension. As
it had been difficult to control her paroxysms of AF, various
drugs had been added incrementally. When she was admitted,
she had been taking betaxolol 5 mg, disopyramide 200 mg,
pilsicainide 100 mg, and amlodipine 8 mg for 10 months.

At the time of admission, the patient was drowsy and her
blood pressure was unmeasurable. Her last ECG recorded
at a prior routine hospital visit had shown sinus rhythm of
50–60 beats/minute, while ECG on admission demonstrated
sinus arrest and ventricular/junctional escape beats with
pauses of 4.7 seconds (Figure 1). Mechanical ventilation
and transcutaneous pacing were performed immediately and
dopamine, noradrenaline, adrenaline, and atropine sulfate
were administered intravenously. Laboratory examination
revealed creatinine levels at 1.91 mg/dL, aspartate aminotransferase at 643 IU/L, alanine transaminase at 396 IU/L,
and K (potassium) at 4.1 mEq/L. Echocardiogram showed
no specific findings with normal left ventricular contraction.
Emergent coronary angiogram disclosed no stenosis. All
drugs were discontinued. Her ECG returned to sinus rhythm
with a heart rate of 60 beats/minute 2 hours later. Her blood
pressure also improved to 114/62 mmHg. All therapies were
terminated 26 hours later. Her renal and liver function indices
gradually returned to normal range. Her heart rate returned
to approximately 80 beats/minute (Figure 5), at which point
paroxysmal AF with rapid ventricular response recurred.
Aprindine 20 mg and verapamil 80 mg were therefore started
with caution. No bradycardia recurred during follow-up.

Discussion
Major findings
We present data on eight patients who had suffered clini-
cally significant and symptomatic drug-induced bradycardia,
responsible for the development of syncope, cardiogenic
shock, and heart failure. All of our patients were over 70 years
old and taking beta-blockers at the time of presentation. Their
ECGs exhibited heart rates of 20–49 beats/minute, sinus
bradycardia or sinus arrest with escape rhythms, and normal
QRS duration. Four of the five patients who were also on Na
channel-blockers required more than drug discontinuation;
they required cardioactive medication, temporary pacing, and
in one patient, mechanical ventilation. None of the patients
had recurrence of bradycardia during the follow-up period.

Bradycardia due to proarrhythmic effects
Proarrhythmia is a potential problem that may contribute
to increased mortality during antiarrhythmic therapy. Bradycardia is a possible side effect of all classes of
antiarrhythmic drugs.\textsuperscript{1,2} However, it is known that drug-induced bradycardia usually does not appear in patients with normal sinus node function and normal atrioventricular conduction.\textsuperscript{11,12} Previous reports found that advanced age, combined drug therapy, the period during the initial 24 hours after initiation of drug therapy, decreased systolic performance, and female were predictors of proarrhythmia,\textsuperscript{1,2} while preexisting conduction disturbance,\textsuperscript{11} ventricular arrhythmia,\textsuperscript{11} and combined drug therapy\textsuperscript{9} were associated with drug-induced bradycardia in particular.

<table>
<thead>
<tr>
<th>Group</th>
<th>Symptom</th>
<th>Initial ECG</th>
<th>HR, bpm</th>
<th>BP, mmHg</th>
<th>HF</th>
<th>Treatment</th>
<th>Time to full recovery, hours</th>
<th>Serum K, mEq/L</th>
<th>Serum Cr, mg/dl</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient 1</td>
<td>BB + Na</td>
<td>Chest discomfort</td>
<td>S Arrest + junctional/ventricular escape</td>
<td>23</td>
<td>Unmeasurable</td>
<td>No</td>
<td>Transcutaneous pacing, intravenous cardioactive medication, and mechanical ventilation</td>
<td>26</td>
<td>4.1</td>
</tr>
<tr>
<td>Patient 2</td>
<td>BB + Na</td>
<td>Inability to stand</td>
<td>S bradycardia</td>
<td>34</td>
<td>151/70</td>
<td>Yes</td>
<td>Intravenous atropine</td>
<td>11</td>
<td>4.5</td>
</tr>
<tr>
<td>Patient 3</td>
<td>BB + Na</td>
<td>Syncope</td>
<td>S bradycardia</td>
<td>30</td>
<td>120/40</td>
<td>No</td>
<td>Intravenous atropine</td>
<td>8</td>
<td>4.2</td>
</tr>
<tr>
<td>Patient 4</td>
<td>BB + Na</td>
<td>Impaired consciousness</td>
<td>S bradycardia</td>
<td>20</td>
<td>62/</td>
<td>No</td>
<td>Transcutaneous pacing and intravenous cardioactive medication</td>
<td>3.5</td>
<td>4.7</td>
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<td>Patient 5</td>
<td>BB + Na</td>
<td>Nausea</td>
<td>S bradycardia</td>
<td>26</td>
<td>98/27</td>
<td>No</td>
<td>No</td>
<td>8</td>
<td>4.0</td>
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<tr>
<td>Patient 6</td>
<td>BB</td>
<td>Syncope</td>
<td>S bradycardia</td>
<td>49</td>
<td>169/83</td>
<td>No</td>
<td>No</td>
<td>4</td>
<td>4.2</td>
</tr>
<tr>
<td>Patient 7</td>
<td>BB</td>
<td>Syncope</td>
<td>S arrest + junctional escape</td>
<td>36</td>
<td>Unmeasurable</td>
<td>No</td>
<td>No</td>
<td>3.5</td>
<td>4.9</td>
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<tr>
<td>Patient 8</td>
<td>BB</td>
<td>Syncope</td>
<td>S bradycardia</td>
<td>40</td>
<td>114/51</td>
<td>No</td>
<td>No</td>
<td>8</td>
<td>4.0</td>
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<tr>
<td>Average SD</td>
<td></td>
<td></td>
<td></td>
<td>32</td>
<td>10</td>
<td></td>
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<td>9</td>
<td>7</td>
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</tbody>
</table>

Note: PR interval was not measured because of no P waves.

Abbreviations: AST, aspartate aminotransferase; BB, beta-blockers; bpm, beats per minute; BP, blood pressure; Cr, creatinine; ECG, electrocardiogram; HF, heart failure; HR, heart rate; HT, hypertension; K, potassium; LVEF, left ventricular ejection fraction; mEq, milliequivalent; ND, not done; QTc, corrected QT interval; S, sinus; SD, standard deviation.

Figure 1 The 12-lead ECG on admission in patient 1. The 12-lead ECG shows sinus arrest and ventricular and junctional escape beats with a pause of 4.7 seconds. The QRS width of the junctional escape beat was 97 ms. The V4 lead was disconnected.

Abbreviation: ECG, electrocardiogram.

Figure 2 The 12-lead ECG on admission in patient 2. The 12-lead ECG shows sinus bradycardia of 34 beats/minute with QRS width of 80 ms.

Abbreviation: ECG, electrocardiogram.
Drug-related serious bradycardia

<table>
<thead>
<tr>
<th>Serum AST, IU/L</th>
<th>Serum concentration (therapeutic range)</th>
<th>QRS width on admission, ms</th>
<th>PR interval on admission, ms</th>
<th>QTc on admission</th>
<th>HR after recovery, bpm</th>
<th>QRS width after recovery, ms</th>
<th>PR interval after recovery, ms</th>
<th>QTc after recovery</th>
<th>Follow-up duration, days</th>
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<tbody>
<tr>
<td>643</td>
<td>ND</td>
<td>97</td>
<td>657</td>
<td>70–80</td>
<td>81</td>
<td>179</td>
<td>411</td>
<td>526</td>
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<tr>
<td>240</td>
<td>Flecainide</td>
<td>80</td>
<td>437</td>
<td>70–90</td>
<td>91</td>
<td>245</td>
<td>428</td>
<td>649</td>
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<td></td>
<td>200 ng/mL</td>
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<td>(200–1,000 ng/mL)</td>
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<td>20</td>
<td>ND</td>
<td>83</td>
<td>385</td>
<td>60–70</td>
<td>90</td>
<td>170</td>
<td>416</td>
<td>725</td>
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<tr>
<td>59</td>
<td>Cibenzoline</td>
<td>100</td>
<td>452</td>
<td>60–70</td>
<td>80</td>
<td>182</td>
<td>392</td>
<td>2,074</td>
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<tr>
<td></td>
<td>482 ng/mL (trough, 70–250 ng/mL; peak, 200–800 ng/mL)</td>
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<td>30</td>
<td>Pilsicainide</td>
<td>99</td>
<td>450</td>
<td>55–70</td>
<td>94</td>
<td>145</td>
<td>383</td>
<td>2,475</td>
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<td>1.13 μg/mL (0.2–0.9 μg/mL)</td>
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<td>151</td>
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<td>93</td>
<td>364</td>
<td>60–70</td>
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<td>389</td>
<td>251</td>
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<td>87</td>
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<td>83</td>
<td>288</td>
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<td>27</td>
<td></td>
<td>97</td>
<td>403</td>
<td>60–70</td>
<td>97</td>
<td>188</td>
<td>440</td>
<td>1,548</td>
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<td></td>
<td></td>
<td>91.5</td>
<td>429.4</td>
<td>62–74</td>
<td>87.8</td>
<td>172.8</td>
<td>411.1</td>
<td>1,036</td>
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<td></td>
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<td>8.2</td>
<td>106.8</td>
<td>7</td>
<td>6.8</td>
<td>35.9</td>
<td>30.4</td>
<td>888</td>
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</tbody>
</table>

Beta-blockers cause bradycardia by antagonizing the actions of catecholamines produced by the sympathetic nerves at the cell receptor. Five of our patients were on the beta-blockers metoprolol or carvedilol. Emergent bradycardia associated with the use of metoprolol and carvedilol in clinical practice was 18 per 1000 person-years in one study. In patients with heart failure, incidence of life-threatening bradycardia induced by carvedilol was 0.9% (Carvedilol Prospective Randomized Cumulative Survival [COPERNICUS] study), while incidence of bradycardia necessitating withdrawal of metoprolol was very similar at 0.8% in the Metoprolol controlled release/extended release Randomized Intervention Trial (MERIT-HF). None of our patients had heart failure or any other structural heart disease.

Figure 3 The 12-lead ECG on admission in patient 4. The 12-lead ECG shows sinus bradycardia of 20 beats/minute with QRS width of 100 ms. Abbreviation: ECG, electrocardiogram.

Figure 4 The 12-lead ECG on admission in patient 7. The 12-lead ECG shows sinus arrest and junctional escape beats of 36 beats/minute with QRS width of 93 ms. The 4th QRS complex is thought of as a sinus beat with the preceding P wave. Abbreviation: ECG, electrocardiogram.
Mechanism of sinus node dysfunction caused by sodium channel blockers

The pacemaker activity of the sinus node cells arises from spontaneous diastolic depolarization (the pacemaker potential) that relies on the concerted action of many cellular elements and processes, including ion channels, ion pumps and exchangers, cyclic adenosine monophosphate and Ca²⁺ homeostasis, and a variety of modulatory factors. It is known that Na channel blockers may suppress sinus node function.⁷,¹⁸ However, the ionic mechanisms responsible for this suppression have not been conclusively defined yet. We discuss several possible mechanisms.

Ca channel blockade by Na channel-blockers

In dogs, cibenzoline had no effect, but produced sinus bradycardia when combined with beta-blockers, suggesting calcium channel antagonism.¹⁹ One other study suggested that mexiletine had considerable Ca channel blocking action at therapeutic concentration,²⁰ while pilsicainide, despite being a pure Na channel blocker, inhibited Ca current at a plasma concentration higher than is therapeutic in vitro.²¹

Na currents may be necessary for conduction of sinus node impulses

Studies show that the sinus node action potential is initiated in the center of the node (Ca channel-dependent) and conducted to the surrounding atrial muscle via the peripheral regions (Na channel-dependent).²²,²³ Na channel block with tetrodotoxin has been shown to cause sinus node dysfunction, ie, a slowing of sinus node pacemaking, a slowing of sinus node conduction, and sinus node exit block.²⁴,²⁵

Inhibition of ryanodine receptor-mediated Ca²⁺ release by Na channel-blockers

Spontaneous local submembrane Ca²⁺ release through the ryanodine receptor (RyRs) in the sinus node cells activates an inward Na-Ca²⁺ exchange current, which contributes to accelerating diastolic depolarization rate.²⁶ Flecaïnide and propafenone have been reported to suppress such Ca²⁺ release by inhibiting the ryanodine receptor, which may contribute to a decelerated pacemaking rate.²⁷,²⁸ Aprindine and cibenzoline have been reported to inhibit Na-Ca²⁺ exchange current in a concentration-dependent manner in vitro, which would likewise result in suppression of pacemaking rate.²⁹,³⁰

QRS duration, sex, age, and drug duration

It is well-known that Na channel-blockers can cause ventricular arrhythmias, namely, sine-wave-shaped ventricular...
tachycardia with wide QRS duration. QRS width is commonly used as a marker of magnitude of Na channel-blocking effects. Therefore, we measured QRS duration in our patients’ admission ECGs and after antiarrhythmic drug discontinuation. Although we found narrowing of QRS in some patients following drug discontinuation, the absolute value of QRS duration at admission was normal and not suggestive of Na channel-blocker overdose. We are aware of only one study reporting QRS width lengthening during drug-induced bradycardia, for the drug pilsciaainide.7

Six of our eight patients were female. The number of patients was too small to say whether females were more likely to suffer from drug-induced bradycardia, but other known sex differences do exist in proarrhythmia, eg, for torsade de pointes.31 In torsade de pointes, the sex difference arises from differences in potassium current density. A significant association between amiodarone-associated bradycardia and female sex has been reported,8 but we know of no sex difference studies for Na current density.

It is well-known that older age is a risk factor for proarrhythmia.12 In our series, all patients were over 70 years old. This is likely due to several factors: increased fibrosis and a decrease of pacemaker cells in the nodal area, likelihood of being on multiple drugs, and diminished mental capacity leading to poor adherence. Many of our patients were taking antiarrhythmic medications for tachyarrhythmia that needed to be controlled. It may be important to consider non-pharmacological treatment for tachycardia, even in the elderly.

Proarrhythmia is said to occur usually within several days of beginning a drug or increasing the dose.32 However, most of our patients exhibited bradycardia only after long-term drug treatment. Of the five BB+Na group patients, there was one participant who had been taking their medication for 10 days, but the other four patients had been taking their medication for 300 days or more. The occurrence of proarrhythmia later in drug therapy might suggest progression of disease or may result from other precipitating factors. However, none of our patients had any identifiable precipitating causes of their bradycardia. Furthermore, their symptoms were of rapid onset. Therefore, it is not clear what signs the physician could have been watching for in predicting and preventing bradyarrhythmia.

Limitations
The limitations of this study were several. First, this is a retrospective study done at a single site with small sample size. Second, not all patients underwent evaluation of sinus node function by EPS or Holter monitoring. Patients might have had asymptomatic bradycardia that would have been identified during 24-hour ECG monitoring. Although they might have been predisposed to latent sinus node dysfunction, their sinus rates were within normal limits both before start and after discontinuation of their medications. Therefore, it is thought that their severe bradycardia was newly caused by antiarrhythmic drugs. In any case, they need careful and continuous follow-up for sinus node function. Third, the plasma concentration of Na channel-blockers was not measured in all patients. The exact plasma concentrations of drugs that might cause significant bradycardia are unidentified. It is also unknown whether serum concentrations necessarily correlate with considerable bradycardia.

Conclusion
Although severe bradycardia due to proarrhythmic effects of Na channel-blockers is infrequent, it may occur in combination with beta-blockers, causing a possibly fatal outcome. We found this to occur with Na channel-blockers at a plasma concentration that did not prolong the QRS width. Caution should be exercised in prescribing, especially in elderly patients.

Disclosure
The authors report no conflicts of interest in this work.

References
1. Friedman PL, Stevenson WG. Proarrhythmia. Am J Cardiol. 1998;82(8A):S0N–S8N.