Is there a need for routine testing of ICD defibrillation capacity?

Results from more than 1000 studies


Hospital of the Westfälische Wilhelms-University of Münster, Department of Cardiology and Angiology and Institute for Arteriosclerosis Research, Münster, Germany

Aims Benefits and complications of postoperative implantable cardioverter-defibrillator tests are controversial matters. This study sought to assess the necessity of defibrillation function tests after implantation.

Methods and Results We retrospectively analysed 1007 implantable cardioverter-defibrillator tests in 587 systems and 556 patients. Nine hundred and thirty implantable cardioverter-defibrillator tests (89·4%) were routinely performed. Seventy-one tests (7%) were performed after a change in the antiarrhythmic drug regimen and six tests (0·60%) because of a suspected dysfunction of the implantable cardioverter-defibrillator. During routine tests, four systems (0·4%) failed to defibrillate the patient. However, in all but one test, abnormalities of the system had been observed before the test. After the addition of antiarrhythmic drugs, two of 71 implantable cardioverter-defibrillator systems (2·8%) failed to defibrillate the patient. One of six systems tested due to a suspected dysfunction failed to defibrillate the patient. During 16 tests (1·6%), complications occurred.

Conclusions Our experience demonstrates that postoperative tests of the defibrillation function of implantable cardioverter-defibrillators rarely reveal dysfunctions. As testing is unpleasant for the patient and not free of complications, tests might be restricted to those patients in whom a dysfunction is suspected and to those patients in whom class I or class III antiarrhythmic drugs have been added to the antiarrhythmic drug regimen.

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Key Words: Implantable cardioverter-defibrillator, implantable cardioverter-defibrillator test, antiarrhythmic drug, implantable cardioverter-defibrillator dysfunction, defibrillation.

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Introduction

Preventing sudden cardiac deaths by implantable cardioverter-defibrillators requires appropriate detection and termination of ventricular fibrillation by the device. To avoid any failure of the device, the defibrillation function has to be routinely tested intraoperatively, before discharge from the hospital, and — at least in some centres — also later during follow-up. Additionally, implantable cardioverter-defibrillator tests are usually performed after changes in antiarrhythmic drug medication or if a dysfunction of the implantable cardioverter-defibrillator system is suspected.

Since the induction and termination of ventricular tachyarrhythmias has potential complications[1-3], is unpleasant for the patient, and adds additional costs to implantable cardioverter-defibrillator therapy, the number of defibrillation tests should be reduced to a minimum. Currently it is unknown when a reevaluation of the defibrillation function of implantable cardioverter-defibrillators is mandatory and if routinely performed whether postoperative tests result in improved safety of implantable cardioverter-defibrillator therapy.
Methods

Patients

Between January 1990 and July 1996, 587 systems with non-thoracotomy leads were implanted in 556 patients at the University Hospital of Münster, including 31 revisions of the implantable cardioverter-defibrillator lead system. The majority of patients were male (n=434, 78%) and their mean age was 57 ± 12 (12–81) years. The underlying heart disease was coronary artery disease in 325 patients (59%), idiopathic dilated cardiomyopathy in 99 patients (18%), and arrhythmogenic right ventricular cardiomyopathy in 28 patients (5%). Sixty-four patients (11%) suffered from other cardiac diseases while no underlying cardiac disease could be identified in 40 patients (7%).

Implanted implantable cardioverter-defibrillator systems

All systems were implanted without thoracotomy. Most patients (n=339, 58%) received only transvenous leads. In 145 patients (25%), a subcutaneous patch and in 103 patients (17%), a subcutaneous array was included in the lead system. Two hundred and eighty devices (48%) were implanted abdominally and 307 (52%) subpectorally. Four hundred and thirty-two devices (74%) were capable of delivering biphasic shocks. The mean intra-operative defibrillation threshold was 12 ± 6 (1–34) Joules.

Implantable cardioverter-defibrillator tests

Implantable cardioverter-defibrillator tests were performed before discharge, during follow-up (according to different study protocols), after revisions of the implantable cardioverter-defibrillator system (e.g. replacement of a non-active device by an active can, additional pace/sense-electrode, etc.), after addition of class I or III antiarrhythmic drugs, or due to a suspected dysfunction of the implantable cardioverter-defibrillator system. Contraindications for postoperative implantable cardioverter-defibrillator tests were neurological disorders (e.g. stroke) in the patients’ history, a non-organized left ventricular thrombus, or a poor clinical condition.

For each implantable cardioverter-defibrillator test, informed written consent of the patient was required. Before the procedure, an X-ray of the lead system was obtained to detect dislocations or fractures of the lead(s). Analgesic and/or sedative agents were used on the patient’s request during the defibrillation test. Before the defibrillation test was performed, sensing during basic rhythm was checked and pacing threshold and pacing impedance were measured. The energy of the first shock was usually programmed to maximum energy or according to different study protocols to values between the maximum energy and the intra-operative defibrillation threshold. All further shocks were programmed to maximum energy. Usually, programmed ventricular stimulation was performed to induce ventricular tachycardia in order to document their rate and the success of antitachycardia pacing. Programmed ventricular stimulation was not conducted in patients without ventricular tachycardias amenable to antitachycardia pacing. If ventricular fibrillation had not been induced during programmed ventricular stimulation, high frequency bursts, T-wave-shock and/or alternating current were applied to induce ventricular fibrillation. If ventricular fibrillation could not be induced, ventricular tachycardias served as substitutes to evaluate the implantable cardioverter-defibrillator’s shocking capabilities. Ventricular tachycardias were classified as fast (CL ≤ 250 ms) poly- or monomorphic and slow (CL > 250 ms) poly- or monomorphic ventricular tachycardias. Retrospectively, the following aspects of the tests were analysed: indication for the implantable cardioverter-defibrillator test; ability of the implantable cardioverter-defibrillator to cardiovert/defibrillate ventricular tachycardia/fibrillation; influence of the results of defibrillation-test on patient management; complications during the test.

Results

Overall results

One thousand and seven implantable cardioverter-defibrillator tests were performed, 573 routinely before discharge (56.9%), 344 1–6 months after implantation (34.2%), 13 after revisions of the implantable cardioverter-defibrillator system, 71 after addition of class I or III antiarrhythmic drugs (7.0%), and six due to a suspected dysfunction (0.6%) (Fig. 1). Seven hundred and sixty-seven tests (76%) were performed in patients with biphasic implantable cardioverter-defibrillators and 240 tests (24%) in patients with monophasic implantable cardioverter-defibrillators. In 539 (53.6%) tests, ventricular fibrillation was induced. In 96 tests (9.5%) fast polymorphic ventricular tachycardia, in seven tests (0.7%) slow polymorphic ventricular tachycardia, in 157 tests (15.6%) fast monomorphic ventricular tachycardia, and in 74 tests (7.3%), slow monomorphic ventricular tachycardia had to serve as a substitute to test the shocking capability of the implantable cardioverter-defibrillator. In 134 tests, no ventricular arrhythmia was inducible (13.3%).

The first shock was programmed to 20 ± 6 (2–36) Joules, all further shocks to maximum energy. The ventricular tachyarrhythmia was terminated by the first shock in 776 tests (88.9%), in 79 tests (9%) by the second shock, in seven tests (0.8%) by the third shock, and in four tests (0.5%) by the fourth shock. In seven tests (0.8%), the ventricular tachyarrhythmia could not be
terminated by the device and necessitated external defibrillation. In all implantable cardioverter-defibrillator systems which failed to defibrillate the patient, revision of the implantable cardioverter-defibrillator system or discontinuation of an antiarrhythmic drug reestablished effective internal defibrillation.

**Routine tests**

Nine hundred and thirty tests (92.4%) were performed routinely. Five hundred and seventy-three (56.9%) tests were performed 9±38 days after implantable cardioverter-defibrillator implantation before discharge, 344 (34.2%) 95±64 days after implantation during follow-up, and 13 (1.3%) after a revision of the system (generator replacement n=9, additional pace/sense electrode n=2; additional subcutaneous array electrode n=1; replacement of defibrillation electrode in the vena subclavian n=1). In 122 tests (13.1%), no ventricular tachyarrhythmia was inducible. In four tests (0.43%) internal defibrillation failed: once before discharge (0.17%), three times during follow-up (0.87%), and in no case after a revision of the implantable cardioverter-defibrillator system (Table 1). No failure of defibrillation but other therapeutically relevant findings were seen in four tests (Table 2). In six (0.65%) routinely performed tests, two shocks with maximum energy were needed to terminate the ventricular tachyarrhythmia, in two patients even four shocks. These eight patients had been among the first patients to receive a transvenous-subcutaneous lead system and monophasic implantable cardioverter-defibrillators. In these patients, intraoperatively either a defibrillator test was not performed or appropriate defibrillation thresholds could not be achieved, or only after testing of several lead configurations. They had not been candidates for a thoracotomy due to their poor clinical condition.

Thirteen implantable cardioverter-defibrillator systems were not tested before discharge, twice due to peri-operative deaths, once due to heart transplantation 3 days after implantation, and in ten patients due to contraindications.

**Tests after a change of the antiarrhythmic drug regimen**

Seventy-one tests (7%) were performed after addition of antiarrhythmic drugs (9±12 months after implantable cardioverter-defibrillator implantation). The drugs added are shown in Fig. 2. In six patients (8.4%), no ventricular arrhythmia was inducible. In two patients (2.8%), internal defibrillation failed (Table 1), once after the addition of amiodarone and once after the addition of flecainide. In both cases, monophasic intra-operative defibrillation thresholds had been sufficient (18 and 15 Joules respectively). In three more patients, the implantable cardioverter-defibrillator test revealed problems which resulted in discontinuation of the antiarrhythmic drug. In one patient, flecainide caused a significant rise in defibrillation requirements. In two patients on flecainide or propafenone, QRS doublesensing during ventricular tachycardia led to shock-therapy instead of antitachycardia pacing. After discontinuation of the antiarrhythmic drugs appropriate implantable cardioverter-defibrillator function resolved in all cases.

**Tests performed due to a suspected implantable cardioverter-defibrillator dysfunction**

Six tests (0.6%) were carried out because of a suspected dysfunction of the implantable cardioverter-defibrillator system. In one patient with a high defibrillation threshold at implant, ischaemically induced ventricular fibrillation could not be terminated by a monophasic implantable cardioverter-defibrillator during a percutaneous transluminal angioplasty (PTCA) 3 years later. The subsequent test confirmed a failure of defibrillation outside an episode of myocardial ischaemia. After implantation of a biphasic device, proper internal defibrillation was reestablished. In three patients, implantable cardioverter-defibrillator tests were performed because undersensing was suspected clinically (n=1) or due to severe deterioration of sensing signals (n=2; R-wave-amplitudes of 2.5 and 2.0 mV,

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**Figure 1** Frequency of indications for implantable cardioverter-defibrillator tests.
### Table 1  ICD tests with failure of defibrillation

<table>
<thead>
<tr>
<th>Indication</th>
<th>Time after implantation (months)</th>
<th>System</th>
<th>Intra-operative DFT (J)</th>
<th>Induced arrhythmia</th>
<th>Energies of shocks applied before external defibrillation (J)</th>
<th>Abnormalities before test</th>
<th>Consequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-discharge</td>
<td></td>
<td>Monophasic; tvsc</td>
<td>20</td>
<td>VF</td>
<td>20, 34, 34</td>
<td>Haematoma below subcutaneous patch</td>
<td>Retesting after absorption</td>
</tr>
<tr>
<td>Routine follow-up</td>
<td>1</td>
<td>Biphasic; tv</td>
<td>25</td>
<td>VF</td>
<td>20, 34, 34</td>
<td>Atypical RV-electrode position</td>
<td>New electrode system</td>
</tr>
<tr>
<td>Routine follow-up</td>
<td>3</td>
<td>Biphasic; tv</td>
<td>10</td>
<td>VF</td>
<td>20, 34, 34</td>
<td>Short circuit between 2 RV-leads implanted in parallel</td>
<td>Extraction of old RV-lead</td>
</tr>
<tr>
<td>Routine follow-up</td>
<td>3</td>
<td>Biphasic; tv</td>
<td>15</td>
<td>VF</td>
<td>20, 34, 34</td>
<td>Significant rise of pacing threshold</td>
<td>Additional subcutaneous electrode</td>
</tr>
<tr>
<td>Amiodarone</td>
<td>19</td>
<td>Monophasic; tvsc</td>
<td>18</td>
<td>VT</td>
<td>34, 34</td>
<td>——</td>
<td>Withdrawal of amiodarone</td>
</tr>
<tr>
<td>Flecainide</td>
<td>7</td>
<td>Monophasic; tvsc</td>
<td>15</td>
<td>VF</td>
<td>20, 34, 34</td>
<td>——</td>
<td>Withdrawal of flecainide</td>
</tr>
<tr>
<td>ICD-dysfunction</td>
<td>33</td>
<td>Monophasic; tvsc</td>
<td>24</td>
<td>VF</td>
<td>20, 34, 34</td>
<td>Failure of internal defibrillation of VF caused by PTCA</td>
<td>Implantation of a biphasic ICD</td>
</tr>
</tbody>
</table>

tv=transvenous defibrillation lead system; tvsc=transvenous-subcutaneous defibrillation lead system; J=Joules; DFT=defibrillation threshold; VF=ventricular fibrillation; VT=ventricular tachycardia; PTCA=percutaneous transluminal coronary angioplasty; RV=right ventricular; ICD=implantable cardioverter defibrillator.

### Table 2  ICD-tests with therapeutic relevant results other than defibrillation failure

<table>
<thead>
<tr>
<th>Indication</th>
<th>Time after implantation (months)</th>
<th>System</th>
<th>Intraoperative DFT (J)</th>
<th>Observation</th>
<th>Consequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-discharge</td>
<td></td>
<td>Monophasic; tvsc</td>
<td>34</td>
<td>First shock (34 J) failed to terminate VF</td>
<td>Replacement of quinidine by sotalol to treat AF</td>
</tr>
<tr>
<td>Pre-discharge</td>
<td></td>
<td>Monophasic; tvsc</td>
<td>20</td>
<td>Inappropriate shocks after successful defibrillation of VF due to AIVR</td>
<td>Administration of β-blocker</td>
</tr>
<tr>
<td>Routine follow-up</td>
<td>3</td>
<td>Biphasic; tv</td>
<td>15</td>
<td>Undersensing of VF resulting in a delay of shock delivery</td>
<td>Committed shock programmed on</td>
</tr>
<tr>
<td>Routine follow-up</td>
<td>3</td>
<td>Monophasic; tvsc</td>
<td>15</td>
<td>Repetitive induction of non-sustained VTs</td>
<td>Prolongation of initial detection period</td>
</tr>
<tr>
<td>Flecainide</td>
<td>8</td>
<td>Monophasic; tvsc</td>
<td>10</td>
<td>First shock (18 J) failed to terminateVF</td>
<td>Withdrawal of flecainide</td>
</tr>
<tr>
<td>Flecainide</td>
<td>1</td>
<td>Biphasic; tv</td>
<td>3</td>
<td>Delivery of shock instead of ATP due to QRS-doublesensing during smVT</td>
<td>Withdrawal of flecainide</td>
</tr>
<tr>
<td>Propafenone</td>
<td>7</td>
<td>Monophasic; tvsc</td>
<td>20</td>
<td>Delivery of shock instead of ATP due to QRS-doublesensing during smVT</td>
<td>Withdrawal of propafenone</td>
</tr>
</tbody>
</table>

tvsc=transvenous-subcutaneous defibrillation lead system; tv=transvenous defibrillation lead system; DFT=defibrillation threshold; J=Joules; VF=ventricular fibrillation; AIVR=accelerated idioventricular rhythm; VT=ventricular tachycardia; ATP=antitachycardia pacing; smVT=slow monomorphic ventricular tachycardia; AF=atrial fibrillation.
Complications

In 16 implantable cardioverter-defibrillator tests, complications occurred (1-6%). Three patients suffered transient neurological disorders. Two patients had a general convulsion immediately or 5 min after shock application, one patient was transiently confused and presented a discrete hemiparesis one day after the test. None of these patients had a history of neurological disorders and no patient suffered from similar symptoms afterwards. One of these patients presented atrial fibrillation during the test which was not converted to sinus rhythm by the shock. A left ventricular thrombus could not be found in any of these patients. One patient reported a deterioration of his short term memory since the implantation of monophasic implantable cardioverter-defibrillator. He was exposed to 15 s of ventricular fibrillation. In three patients, atrial fibrillation with rapid ventricular response was induced which led to inappropriate shocks by the implantable cardioverter-defibrillator. In seven patients (0-7%), either preexisting atrial fibrillation (n=2) or sinus tachycardia (n=4), or an accelerated idioventricular rhythm (n=1) caused inappropriate shocks. One patient vomited after the implantable cardioverter-defibrillator test; in another patient the shock application 5 days after implantation caused a haematoma under the subcutaneous patch electrode requiring surgical revision.

Discussion

This evaluation of 1007 implantable cardioverter-defibrillator tests shows that tests reveal relevant results in only 1-4%. However, the incidence of relevant results is influenced by the indication for the test (Fig. 3).

Routine-tests

The overwhelming majority of tests were performed routinely (92-4%). A failure of defibrillation was very rare (0-43%). In addition, all routinely performed tests which revealed a dysfunction of the system were preceded by clinical abnormalities of the system or abnormalities shown by chest X-ray, ultrasound, or pacing and sensing tests. It is a matter of debate whether a significant (eightfold) rise of the pacing threshold, seen as the only abnormality in one of the four patients, was an indicator for failure of the implantable cardioverter-defibrillator to defibrillate. A very obvious atypical position of the right ventricular lead, which was not recalled by the implanting surgeon, was the potential source for a failure of defibrillation in another patient. Also, a large haematoma under the subcutaneous patch seen in another patient is a potential source of defibrillation failure, as it distorts the electrical field which was tested intra-operatively. In the fourth case, two right ventricular defibrillation leads implanted in parallel caused a short-circuit and led to ineffective internal defibrillation. Spontaneous episodes which could have indicated a short-circuit by low fibrillation impedance had not occurred before the test. In ten tests, a rise of defibrillation energy requirements compared to the intra-operative defibrillation threshold was observed but no therapeutic conclusions were drawn. In some of these patients, especially in the two patients in whom four shocks were needed for successful defibrillation an operative revision of the implantable cardioverter-defibrillator system should have been performed. However, during the era of the first transvenously performed implantations of monophasic implantable cardioverter-defibrillators in these patients, a high defibrillation threshold was accepted intra-operatively due to their poor health status. One of these patients, who needed several shocks for successful defibrillation, is the patient who later re-presented with defibrillation failure during the angioplasty and subsequently received a biphasic implantable cardioverter-defibrillator. Thus, patients with a borderline intra-operative safety margin of defibrillation should be tested routinely at pre-discharge.

Figure 2 Frequency of antiarrhythmic drugs which were added postoperatively to the antiarrhythmic drug regimen and resulted in an additional test of the implantable cardioverter-defibrillator's defibrillation function.
Recommendations for the performance of routine implantable cardioverter-defibrillator tests used to be driven by the request of the manufacturers to ensure the safety of their products, especially as many implantations took place within product evaluation studies. Studies analysing retrospectively the impact of defibrillation tests showed different results. Preliminary results of Le Feuvre et al.\[^5\] showed an implantable cardioverter-defibrillator dysfunction in 0·6% of their tests performed before discharge. They concluded that only patients with an intra-operative defibrillation threshold of more than 18 Joules require an induction of ventricular fibrillation before discharge. These results are supported by a study of Weiss et al. who also recommended routine implantable cardioverter-defibrillator tests only in selected patients (R-wave-amplitude <3 mV)\[^6\]. In contrast, Higgins et al.\[^7\] reported severe dysfunctions during the implantable cardioverter-defibrillator test which could not be predicted ahead in 18 of 227 studies (11%) and recommended continuation of routine pre-discharge and follow-up defibrillation tests. Goldberger et al. reported discharge fibrillation tests in 53 patients\[^8\]. In two patients (3·8%) dysfunctions were detected which required operative system revision (lead dislodgement, increase of defibrillation threshold). During a defibrillation test performed 1 month after implantation ‘important programming changes’ (not defined) had to be done in 10% of the patients.

Our data do not justify routinely performed defibrillation tests at pre-discharge and during follow-up. As complications are not negligible and the quality of life of the patients is inversely related to shocks experienced\[^9\], we suggest performing defibrillation tests only in patients who show:

- intra-operative problems of detection and termination of ventricular fibrillation or spontaneous post-operative episodes,
- a safety margin of less than 15 Joules between the intra-operative defibrillation threshold and the maximum energy provided by the implantable cardioverter-defibrillator (or 10 Joules when defibrillation threshold was tested twice)\[^4\],
- a dislocation of a lead on the chest X-ray before discharge,
- or severely deteriorated sensing signals or pacing thresholds compared to intra-operative values\[^6\].

However, due to the conflicting results by others, a prospective randomized study to analyse the impact and safety of routinely performed defibrillation tests would be appropriate.

**Tests after addition of antiarrhythmic drugs**

Antiarrhythmic drugs may have variable effects on the defibrillation threshold both in experimental studies and in the clinical setting. For sodium channel antagonist drugs, most experimental studies have reported increases in defibrillation threshold, whereas for potassium channel blocking drugs variable effects have been shown\[^10\]–\[^14\].

Sotalol, which was tested in 26 patients, did not cause problems of defibrillation. Though this result corresponds to other studies\[^10\], a larger number of tests is needed before sotalol can be claimed as safe concerning defibrillation requirements. The failure to defibrillate one of 28 patients (3·6%) on amiodarone confirms previous reports\[^11\]–\[^13\]. Thus, defibrillation function
should be tested after administration of amiodarone. In three of four patients addition of flecainide caused adverse test results. In one patient internal defibrillation failed, in another patient defibrillation was still possible but three shocks were needed for termination of ventricular fibrillation, and in a third patient QRS-doublesensing during ventricular tachycardia led to unnecessary shock delivery instead of antitachycardia pacing. Thus, flecainide should be used cautiously in implantable cardioverter-defibrillator patients and requires a defibrillation test as well as careful analysis of endocardial ventricular electrograms to exclude the potential for doublesensing. In ten patients tested after addition of propafenone no difficulties of defibrillation threshold were observed. However, in one patient QRS doublesensing during ventricular tachycardia occurred. The effects of propafenone on the defibrillation threshold are controversial\[^{13,14}\], thus defibrillation tests should be mandatory after the addition of propafenone.

Currently a defibrillation test should be performed once a class-I or class-III antiarrhythmic drug has been added to the drug regimen. However, all cases of increased defibrillation energy requirements observed by us after the addition of an antiarrhythmic drug occurred with monophasic shocks. This observation is supported by a preliminary study of Kopp et al. who found a significant increase of defibrillation threshold with monophasic but not with biphasic defibrillation after the addition of amiodarone\[^{12}\]. Whether testing of the defibrillation threshold after the addition of antiarrhythmic drugs can be abandoned with biphasic devices has to be proven in further trials.

**Implantable cardioverter-defibrillator tests due to a suspected dysfunction**

If there is any doubt about whether an implantable cardioverter-defibrillator system functions as specified, a defibrillation test has to be performed. In five of six patients, the implantable cardioverter-defibrillator test could ensure that the defibrillation function of the system was functioning normally, whereas in one test (17%) dysfunction was confirmed by the test.

**Limitations of the study**

The large number of patients in this report also entails the limitation that due to the long observation period, different test protocols for induction and termination of ventricular fibrillation (e.g. concerning programming of first shock energy) as well as different implantable cardioverter-defibrillator devices (e.g. monophasic or biphasic shocks) were used. Furthermore, the number of implantable cardioverter-defibrillator dysfunctions may be underestimated because in 13% of all tests no ventricular tachyarrhythmias were inducible and ventricular fibrillation was induced only in 54% of all positive tests. Slow monomorphic ventricular tachycardia is known to require much less energy for cardioversion than ventricular fibrillation for defibrillation\[^{15}\]. Another limitation results from the fact that different numbers of shocks have been accepted by the attending physicians involved before external defibrillation was applied (Table 1).

**Conclusions**

Tests of the defibrillation function rarely reveal life-threatening dysfunctions of implantable cardioverter-defibrillators. Since they are unpleasant for the patient and not free of complications, they perhaps should be restricted to those patients in whom a dysfunction is suspected or class-I or -III antiarrhythmic drugs are added. Even taking the limitations of the study into account there is no absolute indication to perform defibrillation tests routinely. Since routinely performed tests of antitachycardia pacing do not seem to be necessary\[^{16}\], all routinely performed inductions of ventricular tachyarrhythmias in implantable cardioverter-defibrillator patients may be obviated in the future. This would improve the acceptance of implantable cardioverter-defibrillators by the patient and reduce costs for implantable cardioverter-defibrillator therapy.

**References**


