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Detection of Myocardial Injury During Transvenous Implantation of Automatic Cardioverter-Defibrillators

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OBJECTIVES The present study was designed to assess the extent of myocardial injury in patients undergoing transvenous implantation of an automatic implantable cardioverter-defibrillator (ICD) using cardiac troponin I (cTNI), which is a highly specific marker of structural cardiac injury.

BACKGROUND During ICD implantation, repetitive induction and termination of ventricular fibrillation (VF) via endocardial direct current shocks is required to demonstrate the correct function of the device. Transthoracic electrical shocks can cause myocardial cell injury.

METHODS Measurements of total creatine kinase (CK), CK-MB, myoglobin, cardiac troponin T (cTNT) and cTNI were obtained before and after ICD implantation in 49 consecutive patients. Blood samples were drawn before and 2, 4, 8, and 24 h after implantation.

RESULTS Elevations of CK, CK-MB, myoglobin, cTNT and cTNI above cut-off level were found in 25%, 6%, 76%, 37% and 14% of patients, respectively, with peak cTNI concentrations ranging from 1.7 to 5.5 ng/ml. Cumulative defibrillation energy (DFE), mean DFE, cumulative VF time, number of shocks as well as prior myocardial infarction (MI) were found to be significantly related to a rise of cTNI. Mean DFE $\geq$ 18 J and a recent MI were identified as strong risk factors for cTNI rise.

CONCLUSIONS During transvenous ICD implantation myocardial injury as assessed by cTNI rise occurs in about 14% of the patients. Peak cTNI concentrations are only minimally elevated reflecting subtle myocardial cell damage. Patients with a recent MI and a mean DFE $\geq$ 18 J seem to be prone to cTNI rise. (J Am Coll Cardiol 1999;34:402–8) © 1999 by the American College of Cardiology

During implantation of automatic implantable cardioverter-defibrillators (ICDs), induction and termination of several episodes of ventricular fibrillation (VF) are required to demonstrate correct sensing and defibrillation properties of the device. It is known from intraoperative transesophageal echocardiographic studies that ventricular function may be temporarily compromised during ICD testing (1–3). However, the extent of permanent myocardial cell damage due to intraoperative testing is unclear. Also, it is not known which kind of patients are particularly prone to suffer myocardial cell injury during implantation, nor is it known what number of ICD tests are required to cause myocardial cell damage. Hence, assessment of the degree of myocardial cell damage due to ICD testing was the purpose of this study.

Recently, sensitive and specific markers of structural myocardial injury have been developed and introduced into clinical practice that overcome the drawbacks of creatine kinase (CK) and CK-MB measurements, that is, lack of cardiac specificity and unfavorable time course (4–10). Cardiac troponin I (cTNI) and cardiac troponin T (cTNT) are new serum markers that are sensitive and highly specific to detect myocardial cell injury (11–18). Both markers are regulatory proteins associated with the actin/myosin filaments of striated muscle and are released from the cell in the presence of myocardial necrosis in close relation to the degree and quantity of myocardial cell damage. With progressively higher levels of these markers, the magnitude of myocardial necrosis increases, providing further prognostic importance (11,19–23).

However, unlike cTNT, cTNI is not expressed in skeletal muscle during neonatal development. Therefore, cross-reactivity of cTNI monoclonal antibodies with skeletal muscle forms is not likely to occur and has not yet been reported (24–27). Accordingly, elevations of cTNI do not

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Abbreviations and Acronyms

CAD = coronary artery disease
CK = creatine kinase
cTNI = cardiac troponin I
cTNT = cardiac troponin T
DFE = defibrillation energy
DFT = defibrillation threshold
ICD = implantable cardioverter-defibrillator
LVEF = left ventricular ejection fraction
MI = myocardial infarction
VT/VF = ventricular tachycardia/ventricular fibrillation

occur in serum of healthy subjects or even in patients with skeletal muscle disease or renal failure unless acute myocardial injury is present (28–30). Given these features of cTNT and cTNI as markers of myocardial necrosis, the present study was designed to assess the extent of myocardial cell damage in patients undergoing transvenous implantation of an automatic ICD using the previously mentioned conventional and new serum markers.

PATIENTS AND METHODS

Patients. A total of 49 consecutive patients undergoing transvenous implantation of an ICD were enrolled in the study. All patients gave written informed consent to the procedure. Patient characteristics are detailed in Table 1. Thirty of 37 patients suffering from coronary artery disease (CAD) had a history of myocardial infarction (MI); 6 of these MIs had occurred within the last six months before implantation. Revascularization procedures such as angioplasty, coronary artery stenting or bypass grafting had been completed in all CAD patients before ICD implantation. None of these patients had stable or unstable angina. Twelve of 49 patients had normal coronary arteries, that is, 8 patients with dilated cardiomyopathy, 2 patients with idiopathic ventricular fibrillation (VF), 1 patient with valvular heart disease and 1 patient with right ventricular dysplasia. Twelve of 49 patients had impaired renal function, with serum creatinine ranging from 1.4 to 8.9 mg/dl. In all patients, left ventricular mass was estimated by echocardiography using the penn-cube formula (31). Mean left ventricular mass was 319.7 ± 117.6 g. Left ventricular ejection fraction (LVEF) measured either by angiography or echocardiography was 33.8 ± 16.4%.

Table 1. Patient Characteristics

	All Patients (n = 49)
Age (yrs)	62.2 ± 9.9
Sex (male/female)	41/8
LV ejection fraction (%)	33.8 ± 16.4
LV mass (g)	319.7 ± 117.6
Cardiovascular disease	
CAD	37
Prior MI	30
Dilated CMP	8
Others	4

Data are presented as mean ± SD or number of patients.
CAD = coronary artery disease; CMP = cardiomyopathy; LV = left ventricular; MI = myocardial infarction.

Indication of ICD implantation was 1) documented, unstable, sustained ventricular tachycardia (VT) in 17 patients or documented VF in 16 patients; 2) spontaneous nonsustained VT with inducible, sustained, unstable VT during electrophysiologic study in 15 patients; and 3) severe syncope in the post-MI phase in one patient. None of the patients showed evidence of acute MI perioperatively as assessed by serum markers and routine electrocardiogram or had ICD discharges within the first 24 h after implantation.

Implantation procedure. The ICDs used were a Jewel Model 7219 in 4 of 49 patients, Model 7220 in 17 of 49 patients, Model 7221 in 10 of 49 patients, Model 7223 in 14 of 49 patients, and a GEM DR 7271 (Medtronic, Minneapolis, Minnesota) in 4 of 49 patients, respectively. Leads used were tined, steroid-eluting electrodes in 33 of 49 patients (67%) and screw-in electrodes in 16 of 49 patients (33%). The lowest energy required to terminate VF was defined "defibrillation threshold" (DFT). The DFT testing was performed using a binary search algorithm starting at an energy of 12 joules (J) (32). Implantation criteria were met if the DFT was ≤22 J, or, if the DFT was >22 J, if two subsequently induced VF episodes could be defibrillated successfully with ≤24 J. If the patient failed to meet implantation criteria, repositioning of the ventricular electrode was performed before retesting. An additional lead system (e.g., superior vena cava lead or subcutaneous patch electrode) was required in four patients to fulfill implantation criteria. Reversed polarity was tested in 36 of 49 patients after assessment of the initial DFT. If VF proved to be converted successfully at a lower energy level using reversed polarity, further DFT testing with reversed polarity was performed.

Evaluation of serum markers. Blood specimens were obtained preoperatively in all patients and included measurements of total CK activity, CK-MB activity, myoglobin, cTNT and cTNI, respectively. The measurements were repeated 2, 4, 8 and 24 h after surgery in all patients.

Venous blood samples were drawn into tubes and centrifuged at 4000*g* for 5 min. Serum was stored at −24°C up to 72 h, thawed once and assayed in batches. Assays and measurements were performed and interpreted by individuals blinded to the clinical data.

Total CK activity (upper reference limit 80 U/l) was measured on a BM/Hitachi 717 automatic analyzer using a kinetic-enzymatic assay (CK NAC-activated, Boehringer Mannheim, Germany) according to an "optimized standard method" (33). The CK-MB activity (upper reference limit 10 U/l) was determined using a commercially available

Table 2. Comparison of Mean Baseline and Peak Values of All Serum Markers

	Baseline Values Preoperatively*	Peak Values Postoperatively*	p-Value
Total CK activity (U/l)	20.0 ± 22.3 (4–126)	89.7 ± 161.9 (19–1124)	< 0.0001
CK-MB activity (U/l)	2.4 ± 1.6 (0–8)	5.1 ± 2.4 (1–12)	< 0.0001
CK-MB/total CK (%)	19.0 ± 16.7	9.9 ± 7.4	0.0002
Myoglobin (μg/l)	74.1 ± 228.2 (25–1584)	261.0 ± 779.3 (38–5517)	< 0.0001
Cardiac troponin T (ng/ml)	0.05 ± 0.13 (0.02–0.87)	0.26 ± 0.93 (0.02–6.46)	< 0.0001
Cardiac troponin I (ng/ml)	0.3 ± 0.1 (0.3–0.7)	0.8 ± 1.0 (0.3–5.5)	< 0.0001

*Mean ± SD (range).
CK = creatine kinase.

immuno-inhibition assay (CK-MB NAC-activated, Boehringer Mannheim, Germany).

Myoglobin was measured using a commercially available immunonephelometric assay (N Latex Myoglobin Reagent, Behringwerke Marburg, Germany) with the upper reference limit of 70 μg/l and the lower limit of detection of 25 μg/l.

Cardiac troponin I was measured by the Stratus II fluorometric enzyme immunoassay (Dade International, Miami, Florida), which utilizes two monoclonal antibodies specific for two different epitopes on the cTNI molecule. No cross-reactivity has been observed with cTNI found in human skeletal muscle (29). In healthy subjects without evidence of cardiac disease, cTNI concentration was less than the minimum detectable concentration of the assay, which is 0.35 ng/ml. Studies performed with this assay on samples of hospitalized patients due to chest pain have defined the upper reference limit for patients without MI to be 1.5 ng/ml based on a 95% cutoff value by nonparametric analysis (34–36). Therefore, the diagnostic cutoff value was defined to be 1.5 ng/ml in our study.

Cardiac troponin T was measured by an enzyme-linked immunosorbent assay with an ES 600 analyzer using streptavidin-coated tubes (Boehringer Mannheim, Germany). The capture antibody is specific for cTNT, whereas the detection antibody shows a 12% rate of cross-reactivity with skeletal muscle troponin T (16). Troponin T levels above the normal range may be found in samples of patients with chronic renal failure and patients on dialysis (28). The lower limit of detection of the assay as stated by the manufacturer is 0.02 ng/ml; the diagnostic cutoff for cTNT is 0.1 ng/ml.

Statistical analysis. Analyses were performed using a commercially distributed software package (Statview, version 4.5, Cherwell Scientific Publishing, Oxford, United Kingdom, and PCS, version 2.1, Topsoft, Hannover, Germany) including paired and unpaired nonparametric tests. Comparison of demographical data was performed with a Mann-Whitney *U* test for continuous variables and a chi-square test (or Fisher exact test if numbers were small) for categorical variables. To test for the difference in serum markers at baseline and after ICD implantation a Wilcoxon signed rank sum test was used. Relationships between variables were examined using univariate (Fisher exact test) and multivariate analysis (logistic regression model for dichotomous variables). Variables entered into the multivariate model were those that gave statistically significant results in the univariate analysis. In addition, LVEF ≤30% and mean defibrillation energy (DFE) ≥18 J were used in the multivariate analysis since these variables represent widely used and clinically important parameters. All data are expressed as mean ± SD. A p-value <0.05 was considered statistically significant.

RESULTS

Evaluation of all serum markers. In total, a significant rise from mean baseline values measured preoperatively to mean peak values measured postoperatively was observed in all serum markers. However, the ratio of CK-MB to total CK showed a significant decrease postoperatively (Table 2). Elevations of serum markers above cutoff value were found in 12 of 49 (25%) patients for CK, 3 of 49 (6%) patients for CK-MB, 37 of 49 (76%) patients for myoglobin, 18 of 49 (37%) patients for cTNT and 7 of 49 (14%) patients for cTNI, respectively. Accordingly, a threefold rise of CK, CK-MB, myoglobin, cTNT and cTNI from baseline to peak values was seen in 10 of 12 (83.3%), 2 of 3 (66.7%), 23 of 37 (62.2%), 13 of 18 (72.2%) and 7 of 7 (100%) patients, respectively. The cTNT concentrations above cutoff level were found to be related to increased serum creatinine values in our studied population. Eight of 18 patients with peak cTNT ≥0.1 ng/ml showed impaired renal function, with serum creatinine >1.3 mg/dl as compared to 4 of 31 patients with peak cTNT concentrations below 0.1 ng/ml ($p = 0.04$). Mean serum creatinine was 2.5 ± 2.6 mg/dl in

Table 3. Characteristics of the 49 Studied Patients According to Levels of Cardiac Troponin I

Parameters	All Patients* (n = 49)	cTNI ≥ 1.5 ng/ml* (n = 7)	cTNI < 1.5 ng/ml* (n = 42)	p-Value
Cardiovascular disease				
CAD	37/49	7/7	30/42	NS
Prior MI	30/49	7/7	23/42	0.03
MI within the last 6 months	6/49	3/7	3/42	0.03
LV ejection fraction (%)	33.8 ± 16.4	28.9 ± 12.9	34.6 ± 16.9	NS
LV mass (g)	319.7 ± 117.6	335.3 ± 59.2	316.1 ± 128.0	NS
LVEDD (mm)	63.2 ± 9.1	62.7 ± 7.7	63.3 ± 9.4	NS
Serum creatinine (mg/dl)	1.6 ± 1.7	1.3 ± 0.3	1.7 ± 1.8	NS
Additional leads	4/49	3/7	1/42	0.007
Active lead fixation	16/49	2/7	14/42	NS
Number of lead positions	1.7 ± 1.0	2.9 ± 1.3	1.5 ± 0.9	0.009
Cumulative DFE (J)	111.2 ± 62.7	203.0 ± 107.7	95.9 ± 35.1	0.01
Mean DFE (J)	15.4 ± 4.1	20.0 ± 4.8	14.6 ± 3.4	0.005
Peak DFE (J)	30.8 ± 6.2	33.6 ± 1.6	30.4 ± 6.6	NS
Cumulative VF time (s)	61.6 ± 28.1	94.1 ± 47.6	56.1 ± 19.9	0.01
Number of VF inductions	4.8 ± 1.5	6.1 ± 2.3	4.6 ± 1.2	NS
Number of shocks	7.0 ± 2.5	10.4 ± 4.5	6.5 ± 1.5	0.04
Operation time (min)	94.9 ± 41.5	149.3 ± 70.4	85.8 ± 26.5	0.008

*Data are presented as mean ± SD or number of patients.

CAD = coronary artery disease; DFE = defibrillation energy; EDD = end diastolic diameter; LV = left ventricular; MI = myocardial infarction; NS = not significant; VF = ventricular fibrillation.

patients with cTNT ≥0.1 ng/ml as compared to 1.1 ± 0.3 mg/dl in patients with cTNT <0.1 ng/ml ($p = 0.007$). However, cTNI concentrations were unrelated to serum creatinine values (Table 3).

In patients who received screw-in leads (16 of 49), CK rose from 29.4 ± 34.3 to 144.7 ± 274.8 U/l ($p = 0.0004$), CK-MB from 2.2 ± 1.3 to 5.5 ± 3.3 U/l ($p = 0.001$), myoglobin from 141.0 ± 385.9 to 513.2 ± 1350.2 μg/l ($p = 0.0004$), cTNT from 0.11 ± 0.22 to 0.6 ± 1.6 ng/ml ($p = 0.002$), and cTNI from 0.33 ± 0.1 to 0.8 ± 1.3 ng/ml ($p = 0.02$). In patients with tined leads (33 of 49), CK rose from 15.4 ± 11.2 to 63.0 ± 40.9 U/l ($p < 0.0001$), CK-MB from 2.5 ± 1.8 to 5.0 ± 1.8 U/l ($p < 0.0001$), myoglobin from 39.5 ± 42.2 to 138.4 ± 95.4 μg/l ($p < 0.0001$), cTNT from 0.03 ± 0.03 to 0.1 ± 0.15 ng/ml ($p < 0.0001$), and cTNI from 0.33 ± 0.1 to 0.7 ± 0.7 ng/ml ($p = 0.0007$), respectively. Comparison of mean baseline and peak values of patients with tined versus screw-in leads revealed no significant differences between both groups except for baseline CK and cTNT values. Peak values, however, did not differ significantly in patients with screw-in and patients with tined lead systems.

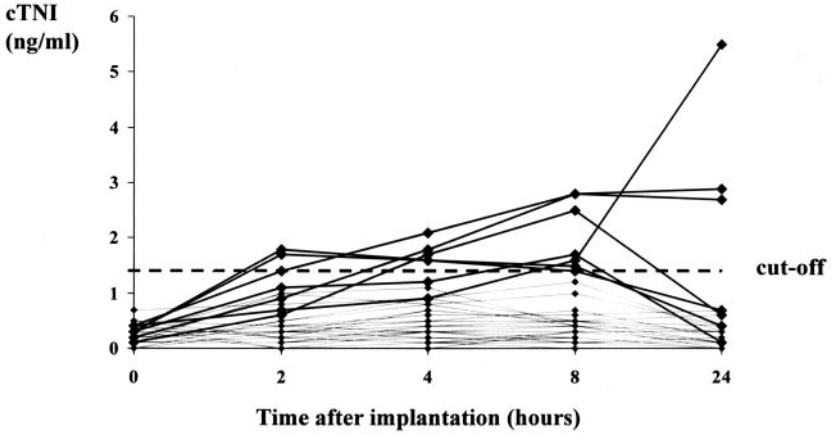

Figure 1. Time course of changes in cardiac troponin I (cTNI) levels for each of the 49 study patients after ICD implantation. Preoperative values are indicated by the first symbol in each curve at 0 h. The dotted line denotes the upper reference limit (cutoff) of the cTNI assay used, which is 1.5 ng/ml. The bulky lines represent patients with cTNI concentrations above cutoff value, whereas patients with cTNI concentrations below cutoff value are denoted by the thin lines.

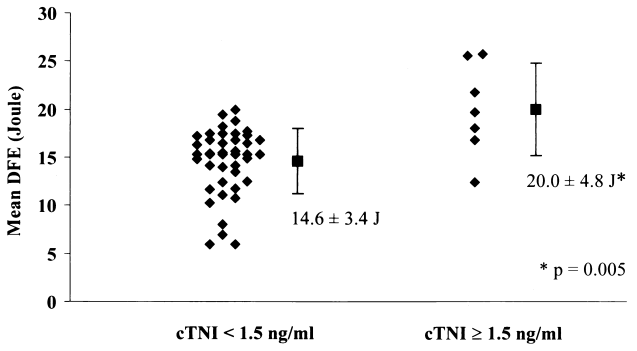

Figure 2. Comparison of mean defibrillation energy applied during ICD testing in patients with and without cTNI concentrations elevated above cutoff value (1.5 ng/ml). cTNI = cardiac troponin I; DFE = defibrillation energy.

Evaluation of cTNI concentrations. The time course of changes in cTNI levels for each patient after ICD implantation is shown in Figure 1. As illustrated, cTNI concentrations showed peak values in 2 of 7 patients 2 h, in 3 of 7 patients 8 h, and in 2 of 7 patients 24 h after ICD implantation ranging from 1.7 ng/ml to 5.5 ng/ml. In 3 of 7 patients, the use of additional leads was required to fulfill implantation criteria resulting in expanded DFT testing and an increased number of shocks applied. In 1 of 7 patients, dislocation of the ventricular lead occurred intraoperatively after a shock discharge, thus requiring repositioning of the lead and further DFT testing. Clinical parameters of patients with cTNI concentrations ≥1.5 ng/ml are listed in Table 3. Univariate analysis showed cumulative DFE, mean DFE, cumulative fibrillation time, number of shocks, prior MI and recent MI within the last six months, use of an additional lead system, number of lead positions as well as operation time to be significantly related to cTNI concentrations elevated above cutoff level. A comparison of mean DFE of patients with and without cTNI rise is shown in Figure 2. No relationship to cTNI rise was found as to peak DFE, lead fixation technique, the number of VF inductions, LVEF, left ventricular mass or underlying heart disease (Table 3). Multivariate analysis was performed to identify independent risk factors for cTNI rise (Table 4). Mean DFE ≥18 J proved to be predictive of a rise in cTNI concentrations. The cTNI rise tended to be more frequent in patients with a history of acute MI within the last six months before ICD implantation. According to the odds ratio given in Table 4, the risk of cTNI rise is considered approximately 33-fold in patients with a mean DFE ≥18 J and 10-fold in patients with a recent MI. Cumulative DFE, cumulative fibrillation time, number of shocks per patient as well as LVEF ≤30% were not predictive of cTNI rise.

Evaluation of follow-up data. In the perioperative period, 1 of 7 patients (14.3%) with cTNI levels above cutoff value and 7 of 42 patients (16.7%) with cTNI concentrations below 1.5 ng/ml experienced appropriate shock discharges ($p = 1.0$). During follow-up, 1 of 7 patients (14.3%) with cTNI and 15 of 42 patients (35.7%) without cTNI rise received appropriate shocks within the first six months after ICD implantation ($p = 0.4$). The mean number of shock discharges per patient was 1.1 ± 3 in patients with elevated cTNI levels as compared to 2.9 ± 6 in patients with cTNI levels below cutoff ($p = 0.38$). None of the seven patients with elevated cTNI concentrations died during follow-up as compared to 5 of 42 patients without cTNI rise ($p = 0.6$).

DISCUSSION

During implantation of ICDs, both induction and termination of several episodes of VF are required to test the correct function of the device. It has been reported from intraoperative transesophageal echocardiographic studies that ventricular function can be temporarily compromised during ICD testing (1–3). However, there is less information available about the degree and quantity of permanent myocardial cell injury caused by ICD testing. Because transvenous implantation procedures are less traumatic than thoracotomy approaches using epicardial patch electrodes, elevation of cardiac cell markers may not result from direct mechanical trauma but is rather due to intraoperative endocardial ICD testing. Hence, this prospective study was

Table 4. Analysis of Risk Factors for cTNI Rise Above Cutoff Level (Multivariate Analysis)

	Odds Ratio	95% Confidence Interval	p-Value
MI within the last 6 months	9.83	0.31–309.99	NS
LVEF ≤30%	3.49	0.14–88.08	NS
Additional leads	0.17	0.00–4049.99	NS
Number of lead positions	2.8	0.42–18.52	NS
Cumulative DFE	1.0	0.99–1.02	NS
Mean DFE ≥18 J	33.2	1.05–1049.75	0.047
Cumulative VF time	1.0	0.9–1.12	NS
Number of shocks	1.15	0.31–4.25	NS
Operation time	1.02	0.96–1.07	NS

DFE = defibrillation energy; J = joule; LVEF = left ventricular ejection fraction; MI = myocardial infarction; NS = not significant; VF = ventricular fibrillation.

undertaken to assess the extent of myocardial cell injury in patients undergoing DFT testing during transvenous ICD implantation using conventional and new serum markers of myocardial necrosis.

Assessment of all serum markers. A significant rise of serum markers was found in all 49 patients postoperatively with elevations of CK, CK-MB, myoglobin, cTNT and cTNI above cutoff level in 25%, 6%, 76%, 37% and 14% of the patients, respectively. Unlike CK and CK-MB, cTNT and cTNI have been demonstrated to be sensitive and highly specific markers for cardiac cell injury (11–18). However, recent studies reported increased cTNT but normal cTNI concentrations in patients with chronic renal failure and skeletal muscle disease without evidence of myocardial injury (28–30,37,38). Moreover, cTNT concentrations above cutoff level were also found to be significantly related to increased serum creatinine concentrations in our study population. Thus, cTNI was considered the most sensitive and cardio-specific marker to assess myocardial cell damage.

Assessment of cTNI. Increase of cTNI concentrations above cutoff level was seen in 7 of 49 patients (14%) after ICD implantation, with peak values ranging from 1.7 to 5.5 ng/ml indicating the presence of myocardial necrosis. Unlike patients with transmural or non-Q-wave MI, cTNI concentrations were only minimally elevated in our study group. Because the amount of cTNI concentrations is known to be related proportionally to the degree of myocardial cell injury (11,23), peak cTNI concentrations measured in our patient group reflect only subtle myocardial injury. These minor cTNI elevations should not be interpreted as possible ischemic or mechanical cardiac injury. The fact that cTNI elevations were unrelated to the type of underlying heart disease and technique used for lead fixation suggests that cTNI elevations are probably due to defibrillation or fibrillation-related cardiac injury. Moreover, tined leads were used in most of the patients that are known to be less traumatic than screw-in leads.

The fact that minor degrees of myocardial cell injury can be induced by electrical shocks is not unexpected and has been demonstrated previously in patients after high-energy transthoracic cardioversion (39–41). Recently, Allan et al. (39) reported on 3 of 38 patients (7.9%) with elevated cTNI concentrations ranging in value from 0.8 to 1.5 ng/ml after direct current transthoracic shocks for elective cardioversion of predominantly atrial fibrillation. The incidence of cTNI rise in our patient population after conversion of several episodes of VF was 14%, with peak values ranging from 1.7 to 5.5 ng/ml. The difference may be explained by the higher number of shocks delivered in our patient population (7.0 ± 2.5 vs. 2.1 ± 1.2 shocks per patient) and the different modalities shock energy was delivered (endocardial vs. transthoracic application). In addition, blood samples were started to be drawn 8 h after cardioversion in the study of Allan and co-workers (39). Because cTNI may peak earlier, as it has been shown in two patients of our study group, some patients with elevated cTNI levels might have been missed in the other study group.

Analysis of risk factors for cTNI rise. In addition to the overall quantification of myocardial cell damage, we also analyzed risk factors in patients prone to myocardial cell injury due to ICD testing. In 4 of 7 patients with a rise of cTNI, the implantation procedure was "complicated" either by dislocation of the right ventricular electrode, requiring repositioning, or by initial DFTs not fulfilling implantation criteria, thus requiring implantation of additional lead systems. As a consequence, intraoperative DFT testing was expanded in those patients resulting in a higher number of shocks, a higher cumulative DFE, and a longer fibrillation time. It is noteworthy that there was no significant difference in number of VF inductions between patients with and without cTNI rise. Despite testing of reversed polarity in most patients, the mean number of VF inductions did not exceed 4.8 attempts.

Univariate analysis revealed cumulative DFE, mean DFE, cumulative fibrillation time, number of shocks and prior MI indicative for myocardial cell injury. Mean DFE $\geq$18 J and a recent MI within the last six months before ICD implantation were found to be strong risk factors of cTNI rise, with an odds ratio of 33 and 10, respectively. As elevations of cTNI may persist up to 10 days after acute MI, we did not include patients with ischemic events within 10 days before ICD implantation.

In contrast with our findings, no relation of cTNI rise to the number of shocks, cumulative or peak energies was found by Allan et al. (39) in patients after transthoracic cardioversion for atrial fibrillation. This may be due to the low number of patients with cTNI rise after cardioversion. Among many variables it has been demonstrated that the magnitude of myocardial cell damage is also dependent on the time between successive shocks (42). Therefore, special care was taken not to fall short of a minimum of 4 to 5 min between successive arrhythmia inductions in our study.

Assessment of follow-up data. In patients with acute coronary syndromes, cTNI concentrations proved to be of prognostic importance (11,23). In our patient population, however, elevated cTNI concentrations were found not to be related to prognostic parameters such as mortality or shock discharge rate, reflecting the minor degree of myocardial cell injury caused during ICD testing.

Clinical implications. During transvenous implantation of ICDs, myocardial cell damage as assessed by rise of cTNI occurs in approximately 14% of patients. Because cumulative and mean DFE, the number of shocks applied and the cumulative fibrillation time are significantly related to myocardial cell damage, intraoperative DFT testing should be limited to a minimum number of arrhythmia inductions and shocks delivered. Excessive test protocols for scientific purposes should be reconsidered in the light of our results.

Rapid and effective test protocols are preferable—for example, binary-search algorithms. Patients with a recent MI seem to be prone to cTNI rise, although revascularization procedures were performed in each patient prior to ICD implantation. This information is important because prophylactic ICD implantation will become frequent in post-MI patients in the near future.

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