Endomyocardial biopsy is a diagnostic procedure used in patients suspected of having myocarditis or a similar inflammatory heart disease. It involves inserting a thin needle into the heart to obtain a small sample of heart muscle tissue for microscopic examination. This procedure is typically performed under local anesthesia and is generally considered a safe and effective method for diagnosing myocarditis. However, it is important to note that the results of an endomyocardial biopsy are not always definitive and may require additional testing, such as cardiac magnetic resonance imaging (MRI) or endomyocardial biopsy, to confirm the diagnosis.
The study was approved by the ethics committee of our institution.

Statistical Analyses
Baseline characteristics are presented as means±SD or median (min–max) for continuous variables and as frequencies for categorical variables. Follow-up times were calculated from the time point of symptom onset, which was defined as the date of first medical contact because of symptoms that led to the diagnosis of GCM. The time point of diagnosis was defined as the date of myocardial biopsy confirming the diagnosis of GCM. The primary end point of the study was SCD, fatal or aborted. As a secondary end point, we analyzed the composite of SCD and any VT requiring treatment (see above). Life-threatening arrhythmias as the presenting manifestation were not taken as end point events. Cardiac transplantation or death caused by terminal heart failure were considered competing events. Cause-specific cumulative incidence analysis was used to plot the incidence–time curves, and the Gray test was used to analyze group differences in the occurrence of end point events. To analyze the association of end point arrhythmias with characteristics of patients and their disease, the Fine and Gray model was used to calculate subdistribution hazard ratios and their 95% confidence intervals (CI). The validity of proportional hazards assumption was tested by calculating Schoenfeld (partial) residuals and plotting them against follow-up time. The assumption was considered valid if no statistically significant time-dependent correlation was observed. In all analyses, P values <0.05 were considered statistically significant. The statistics was calculated using the Xlstat Biomed (Addinsoft, Paris, France) and R software (R Development Core Team) in cumulative incidence analyses and SPSS–21 for Macintosh (SPSS Inc., IL) in all other tests.

Results
Patient Characteristics
The study population consisted of 35 women (69%) and 16 men aged 52±12 years at symptom onset. Their key characteristics at presentation are summarized in Table 1. Because of the long recruitment period, data on some important variables (NT-proBNP, cTnT, MRI, and PET) were not available for all patients (see Table 1 for details). The form of GCM presentation was sustained VT in 7 patients (14%) and out-of-hospital cardiac arrest because of VF in 4 patients (8%). One of the arrested patients died at the scene of the event and could not be included in further analyses. Half of the patients (52%) had severe left ventricular dysfunction (ejection fraction <35%) at the time of presentation, and nearly all who were studied by modern cardiac imaging had abnormal myocardial LGE on MRI (24 of 25 patients) and focal 18F-fluorodeoxyglucose uptake on PET, suggestive of myocardial inflammation (14 of 15 patients).

Myocardial samples from lifetime diagnostic biopsies were available in 42 patients. Grade 2 to 3 (moderate-to-severe) myocyte necrosis was found in 12 patients (29%) and grade 2 to 3 myocardial fibrosis in 7 patients (17%). The number of eosinophilic cells was graded 2 to 3 in 14 (33%) individuals. Of the 7 patients with myocardial material available only from autopsy or transplantation, grade 2 to 3 necrosis was found in 2 patients and grade 2 to 3 fibrosis in 4 patients.

Treatment
Table 2 summarizes the treatments given to the 50 patients alive at presentation. Forty-two of the 43 patients who...
were diagnosed prior to transplantation or autopsy received GCM-targeted immunosuppressive drugs; 1 patient could not be treated because of an early death. All 50 patients were given β-adrenergic blockers, and 29 of them (57%) received amiodarone for the control of ventricular arrhythmias. A permanent ICD was implanted in 31 patients, of whom 23 and 8 individuals received the device for primary and secondary prevention, respectively. Altogether, 11 of the 50 patients (22%) were considered poor candidates for a permanent ICD because of rapidly progressive heart failure and poor survival probability without early transplantation. Thus, among patients eligible for permanent ICD, 31 of 39 (80%) received the device.

**Total Mortality and Transplantations**

The follow-up time from symptom onset to death, transplantation, or end of study ranged from 0.1 to 161 months (median, 19 months). Over the course of the follow-up, 7 patients died (all of cardiac cause) and 19 patients underwent cardiac transplantation. Five of the 7 cardiac deaths were caused by a fatal arrhythmia and 2 by terminal heart failure and cardiogenic shock. Of the 19 transplantations, 16 were made because of intractable heart failure and 3 mainly because of ventricular tachyarrhythmias defying all therapies.

### Occurrence and Correlates of End Point Arrhythmias

Figure 1 illustrates the cumulative incidence of the primary and secondary end point arrhythmias.

Altogether, 14 of 50 patients suffered a fatal (n=4) or aborted (n=10) SCD with a 1-year and 5-year cumulative incidences of 22% (95% CI 13%–38%) and 26% (95% CI 16%–42%), respectively. Secondary end point arrhythmias were recorded in 27 patients with a cumulative incidence of 41% (95% CI 29%–57%) in 1 year and 55% (95% CI 41%–72%) in 5 years from symptom onset.

These 27 events broke down into 4 fatal SCDs, 8 aborted SCDs, and 15 VTs requiring intervention (antitachycardia pacing by ICD, n=7; defibrillation by ICD, n=3; and external cardioversion or defibrillation, n=5).

Table 3 shows the association of the end point arrhythmias with the clinical, laboratory, and histological characteristics of patients at presentation of their GCM. The data show that the occurrence of SCD was associated with high circulating concentrations of NT-proBNP and cTnT, whereas the composite of SCD and VT was related to moderate-to-severe myocardial fibrosis and to VT or VF as the presenting manifestation. By contrast, arrhythmic events were not statistically significantly associated with age, sex, New York Heart Association class,
left ventricular ejection fraction, grades of myocardial necrosis or eosinophils on diagnostic biopsy, or use of triple drug immunosuppression. Because of the small number of cardiac MRI and PET studies, the association of end point events with these studies could not be assessed. Figure 2 demonstrates the association of SCD with plasma cTnT at presentation, and Figure 3 shows the composite incidence of SCD and VT in relation to the extent of myocardial fibrosis (Figure 3A) and to the presenting GCM manifestation (Figure 3B). The analysis shown in Figure 3B was repeated in the subgroup of 39 patients considered eligible for a permanent ICD (see above). Among them, 31 individuals were free of VT or VF at presentation and, thus, did not have an indication for an ICD as secondary prevention. Their cumulative incidence of SCD or VT was 23% (95% CI 12%–45%) in 1 year and 42% (95% CI 26%–67%) in 5 years of follow-up.

**Observations on Outcome With Antiarrhythmic Therapy**

Amiodarone was given to 29 patients to prevent recurrent symptomatic episodes of VT. It had no clinical effect in 6 patients, reduced the frequency of VT episodes in 14 patients, and produced a complete symptomatic remission in 9 patients. Catheter or surgical ablation for medically uncontrollable VT was attempted in 4 patients. The result was partial in every case: the procedure reduced the recurrences but did not abolish VTs completely. Of the 31 patients who received an ICD, in all, 17 patients had 1 or more appropriate ICD therapies during follow-up (Figure 4). Detailed ICD reports were available on altogether 114 such therapies; they are summarized in Table 4. Four patients (13%) received inappropriate ICD shocks because of supraventricular tachyarrhythmia (3 cases) or sinus tachycardia (1 case). No device infections were observed, despite the strong concomitant immunosuppressive therapy.

**Discussion**

Our present work provides the first systematic analysis of the incidence and risk factors of life-threatening ventricular tachyarrhythmias in GCM. The following observations deserve to be raised in particular. First, as many as 22% of patients presented with either sustained VT or with VF causing cardiac arrest, and these individuals bore a particularly high risk of ventricular arrhythmias also during follow-up. Second,
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the risk of SCD and VT requiring therapy was at its highest during the first weeks from presentation but persisted throughout the disease course and resulted in an incidence as high as 55% at 5 years from symptom onset. Third, fatal SCD was much more common as a cause of death in nontransplanted GCM than terminal heart failure. Fourth, ventricular arrhythmias were associated with plasma cTnT and NT-proBNP at presentation and the extent of myocardial fibrosis on diagnostic biopsy, together with the form of disease presentation. Finally, medical and invasive therapies against VTs appeared variably and at most partially effective. ICDs, instead, reliably terminated life-threatening ventricular tachyarrhythmias, and no patient having the device suffered a fatal SCD.

As reported earlier by Granér et al,9 multiple forms of relatively slow monomorphic VTs are common in individual patients with GCM. VTs are usually inducible at the electrophysiological study, and delayed atrioventricular conduction is also a common concomitant.9 These observations from our center suggest that monomorphic VTs are related to areas of injury, replacement fibrosis, and strands of viable myocardium, providing the substrate for reentry tachyarrhythmias. Recently, the expression of myocardial plakoglobin, a desmosomal protein of the intercalated discs, was found to be reduced in GCM similarly to the findings in arrhythmogenic right ventricular dysplasia and cardiac

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**Figure 2.** Cumulative incidence of fatal or aborted sudden cardiac death (SCD) in relation to the median plasma cardiac troponin-T (cTnT) at presentation. In all, 10 events in 43 patients were analyzed.

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**Figure 3.** Cumulative incidence of sudden cardiac death (SCD) or ventricular tachycardia (VT) requiring therapy (secondary end point) in giant cell myocarditis (GCM) patients with none-to-mild (grade 0–1) vs moderate-to-severe (grade 2–3) fibrosis on diagnostic myocardial biopsy (A) and in patients with vs without life-threatening ventricular tachyarrhythmia at presentation (B). The former analysis (A) was made on 22 arrhythmic events in 42 patients and the latter (B) on 27 events in 50 patients. **VF indicates ventricular fibrillation.**
sarcoïdosis. A role for disrupted myocyte-to-myocyte connections in the high arrhythmogenicity of GCM is, thus, possible but unproven today.

Our analyses showed that SCD during follow-up was associated with markedly elevated circulating cTnT (>130 ng/L) at presentation of GCM, while the composite risk of SCD and VT requiring therapy was linked more to the extent of myocardial fibrosis. These associations, mere statistical as they are, suggest that active myocyte injury may trigger VF, in particular, while myocardial fibrosis of old injury promotes sustained VT. Myocardial injury and scarring eventuate in cardiac dysfunction, which explains the correlation of plasma NT-proBNP with study end points, although the association of left ventricular ejection fraction did not reach statistical significance. As expected, VT or VF as the presenting manifestation correlated with a particularly high risk of life-threatening arrhythmia during follow-up. Although the respective risk in patients free of presenting arrhythmias was less, the incidence of SCD and VT requiring therapy was considerable in these individuals, too. Here our findings seem to contrast sharply with the report by Maleszewski et al of no ventricular arrhythmias during long-term follow-up in patients without arrhythmias at presentation. The contrast is lessened, however, recognizing that Maleszewski et al only included patients who had survived the first year of GCM, that is, the period when the risk of fatal arrhythmias is highest in this disease (see our Figure 1). Still, some discrepancy remains because there were patients in our series first experiencing VT or VF after an uneventful year of the disease (see Figure 3B).

There exist no previous observational let-alone prospective data regarding the treatment of ventricular arrhythmias in GCM. Some case reports have suggested that immunosuppression may suppress arrhythmias, too, but other reports show failures. In our study, the response of VTs to standard amiodarone therapy was inconsistent, although the frequency of recurrences was reduced in most patients. Catheter or surgical ablation was attempted in only a few cases unresponsive to medical management. The procedure diminished the number of VT episodes but did not produce complete long-term remission in any patient. This result may be because of the common existence of multiple reentrant pathways in GCM and also to ongoing inflammation, leading to further fibrosis and new reentrant circuits during the disease course. Our most important observation regarding the treatment of arrhythmias in GCM was the frequency and success of ICD therapies. Altogether, 55% of patients with an ICD experienced appropriate treatments, and of the VT episodes recognized by the device, 80% responded to antitachycardia pacing, minimizing the need of shocks. Even more importantly, in patients with an ICD, the device successfully prevented SCD in all 9 VF episodes encountered. The American College of Cardiology/American Heart Association/Heart Rhythm Society 2012 update on guidelines for device-based therapy gives a Class IIa indication (should be considered) for a permanent ICD in GCM, without specifying other criteria than the diagnosis. The 2015 European Society of Cardiology guidelines on ventricular arrhythmias state that a permanent ICD is not recommended in myocarditis until the resolution of the acute phase, and that a wearable cardioverter defibrillator (life vest) should be considered during recovery. However, they also state that because of the known high arrhythmic risk, ICD implantation might be considered earlier in GCM. Our observations indicate that the absence of VT or VF at presentation does not save the GCM patients from later SCD or VT and that their arrhythmia risk is highest during the early weeks after symptom onset and presentation. The risk is also poorly appreciable from left ventricular ejection fraction, the traditional predictive factor in dilated and ischemic cardiomyopathy. Although markers of myocardial injury and fibrosis can point toward patients with the highest risk, we subscribe to the American College of Cardiology/American Heart Association/Heart Rhythm Society consensus and think that, in GCM, a permanent ICD should be considered and implanted soon after presentation in each patient free of a fulminant course and an early need of transplantation. Selected patients with fulminant GCM considered unsuitable for permanent ICD could be safeguarded with a life vest during the transplant waiting period.

Table 4. Characteristics of 114 Ventricular Arrhythmias Promoting ICD Therapy

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Count (Percentage)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ventricular rate, bpm†</td>
<td>180 (140–250)</td>
</tr>
<tr>
<td>Classified as ventricular fibrillation, n</td>
<td>9/114 (8)</td>
</tr>
<tr>
<td>Classified as monomorphic VT, n</td>
<td>105/114 (92)</td>
</tr>
<tr>
<td>Episodes ended by ATP, n</td>
<td>79/114 (69)</td>
</tr>
<tr>
<td>Episodes with failed ATP (of all ATP treated episodes), n</td>
<td>20/99 (20)</td>
</tr>
<tr>
<td>Episodes with &gt;1 shock, n</td>
<td>8/114 (7)</td>
</tr>
<tr>
<td>Episodes with &gt;2 shocks, n</td>
<td>1/114 (1)</td>
</tr>
</tbody>
</table>

The data are medians (range) or numbers of episodes (%). ATP indicates antitachycardia pacing; GCM, giant cell myocarditis; ICD, intracardiac cardioverter defibrillator; and VT, ventricular tachycardia.

†Includes all episodes of appropriate ICD therapy in 31 GCM patients with ICD reports available for analysis.

‡Only episodes of monomorphic ventricular tachycardia.
The size of our study is both a strength and a limitation of our work. By 2012, <300 cases of GCM had been reported in the literature, and our 51 consecutive patients constitute by far the largest and less selected single-center population of this rare disease. On the other hand, for statistical analyses of incidence and associated factors, the number of patients and end point events remained small, limiting the power of our analyses and excluding the use of multivariate analyses. The general limitations of a retrospective design pertain also to the present work. Patients were recruited over a long period of time, and as Tables 1 and 3 specify, several important variables were not available for analyses in all patients. Representing retrospective observations, the responses of VTs to medical and invasive therapies cannot be considered more than suggestive. The classification of myocardial necrosis and fibrosis on biopsy was based on scoring that relied on visual scrutiny of the biopsy material. Even though an automated quantification method would be theoretically more ideal, the semiquantitative technique is widely used and endorsed by experts in the field.

The use in risk assessment of LGE by cardiac MRI, shown by us and others to work in cardiac sarcoidosis, could not be analyzed here. The reasons were, first, that we only had dichotomous (present/absent) data on myocardial LGE and, second, that the number of studied patients was small (25 of 50), and LGE was present in all except one of them. A larger number of patients and quantitative LGE data are needed for proper analyses.

In conclusion, our study shows that more than half of the patients with GCM experience life-threatening ventricular tachyarrhythmias during their transplant-free disease course. Although presentation with VT or VF was associated with the highest incidence of future arrhythmias, the incidence was considerable also in patients free of VT or VF on admission. Besides history of presentation, the extent of active and old myocardial injury may influence the susceptibility to arrhythmias as suggested by the relation of the end point events to elevated circulating cTnT and to moderate-to-severe myocardial fibrosis at presentation. A permanent ICD seems to constitute an effective modality for the treatment of ventricular tachyarrhythmias and the prevention of SCD in GCM.

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Disclosures
None.

References


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