A novel screening tool to unmask potential interference between S-ICD and left ventricular assist device

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Abstract

Introduction: In patients with a left ventricular assist device (LVAD), the subcutaneous implantable cardioverter-defibrillator (S-ICD) can be an alternative to transvenous ICD systems due to reduced risk of systemic infection, which could lead to extraction of the ICD as well as the LVAD. S-ICD eligibility is lower in patients with LVAD than in patients with end-stage heart failure without LVAD. Several reports have shown inappropriate S-ICD therapy in the coexistence of LVAD and S-ICD. The aim of the present study was to evaluate S-ICD eligibility in patients with LVAD using the established electrocardiogram (ECG)-based screening test as well as a novel device-based screening test to identify potentially inappropriate S-ICD sensing in this specific patient cohort.

Methods and Results: The present study included 115 patients implanted with an LVAD. The standard ECG-based screening test and a novel device-based screening test were performed in all patients. Eighty patients (70%) were eligible for S-ICD therapy with the standard ECG-based screening test. Performance of the novel device-based screening test identified device-device interference in 14 of these 80 patients (12%).

Conclusion: Using a novel extended device-based S-ICD screening method, a small number of patients with LVAD deemed eligible for S-ICD with the standard ECG-based screening test exhibit device-device interference. Careful S-ICD screening should be performed in patients with LVAD, who are candidates for S-ICD therapy, to prevent inappropriate sensing or ICD therapy.

KEYWORDS
device-device interference, ICD, implantable cardioverter-defibrillator, left ventricular assist device, LVAD, S-ICD, S-ICD screening test, subcutaneous ICD
1 | INTRODUCTION

Left ventricular assist devices (LVAD) are increasingly used as destination therapy for patients with end-stage heart failure over the last years, leading to a significant improvement in survival rates and patients’ quality of life. Patients scheduled for LVAD implantation are in most cases already implanted with an implantable cardioverter-defibrillator (ICD), since this patient population is at high risk for sudden arrhythmic death.

The subcutaneous ICD (S-ICD) has evolved to a safe alternative to transvenous systems especially in patients with high risk for infections. S-ICD may be of particular interest in patients with LVAD, since systemic infections are associated with significant morbidity and mortality in these patients.

A recent study showed S-ICD eligibility rates of 73.3% in patients with LVAD. An S-ICD screening test is recommended before S-ICD implantation to evaluate appropriate sensing though not predicting S-ICD efficacy. S-ICD eligibility is examined using a screening test based on the surface electrocardiogram (ECG), namely the manual ECG-based and/or the automated screening test performed using the manufacturer’s programmer. However, ECG quality and interpretation are often challenging in patients with LVAD mainly due to artifacts (Figure 1). More specifically, potential electromagnetic interference (EMI) of S-ICD and LVAD leading to oversensing by the S-ICD has been repeatedly reported but cannot be simulated by the available screening methods.

Therefore, the present study aimed to evaluate a novel S-ICD screening test which could unmask potential device-device interference overcoming the limitations of the available ECG-based screening tests in patients with LVAD.

2 | METHODS

Patients implanted with an LVAD presenting for outpatient routine follow-up at Hannover Medical School were included in the study in a prospective manner. The study complied with the Declaration of Helsinki and was approved by the local ethics committee. All patients gave written informed consent.

Baseline parameters were retrieved from hospital records. A 12-lead ECG was performed in accordance with international standards.

In all patients included in the present study two different S-ICD screening methods (ECG-based screening and a novel device-based screening test) were performed to evaluate potential S-ICD eligibility.

2.1 | Standard ECG-based screening test

The ECG-based screening test represents the standard method for the evaluation of S-ICD eligibility before implantation. Conventional limb electrodes (LA, RA, LL) were placed according to manufacturer recommendations as described elsewhere (Figure 2B). These simulated S-ICD vectors were obtained at gains of 5, 10, and 20 mV/cm at a paper speed of 25 mm/s using an ECG device (MAC 5500; GE Healthcare) in supine and erect position. S-ICD eligibility was evaluated in both left and right parasternal position. Eligibility for S-ICD implantation was defined as at least one vector eligible in left and/or right parasternal position in both supine and erect position.

2.2 | Novel device-based screening test

The novel screening method used a functional S-ICD generator (Emblem S-ICD; Boston Scientific) with therapies programmed off which was connected to an S-ICD lead (S-ICD lead 3501; Boston Scientific). The generator and the connected lead were fixed on the body surface in the appropriate position using adhesive tape (Figure 2C). Contact gel was used to ensure appropriate contact of the sensing electrodes and the skin. The chosen setup simulates the typical in-situ vector configurations of an implanted S-ICD system (Figure 2A). First, the online tracing provided by the S-ICD in this configuration was registered and evaluated for any EMI, annotated as noise from the S-ICD. Second, the screening test was considered positive (eligible for S-ICD), if detection during device interrogation showed correct R wave sensing without signal interferences, oversensing, or undersensing. S-ICD eligibility was met if at least one vector was eligible.

2.3 | Statistical analysis

Continuous variables are presented as mean ± standard deviation. Differences among continuous variables were compared using unpaired t test. Categorical variables are presented as numbers and percentages and were compared among subgroups using χ² test or Fisher’s exact test, accordingly. Values of p < .05 were considered statistically significant. Statistical analysis was conducted using SPSS software version 26 (IBM).

3 | RESULTS

Between September 2016 and March 2018, 115 patients implanted with an LVAD at Hannover Medical School were included. Baseline characteristics are shown in Table 1. S-ICD screening tests were performed 930 days (median) after LVAD implantation.

3.1 | Characteristics of the 12-lead ECG

Twelve-lead ECGs of all 115 patients were obtained. One hundred twelve ECGs (97.4%) could be evaluated and were included in the analysis. Three ECGs were excluded due to artifacts from the LVAD making the analysis impossible. Twenty-seven patients (24%) had a
paced QRS complex. Table 2 summarizes the recorded 12-lead ECG parameters.

### 3.2 | Eligibility for S-ICD implantation

Eighty patients (70%) were eligible for S-ICD implantation with the standard ECG-based screening (Figure 3). Forty-three patients (38%) had ≥2 eligible vectors and 37 patients (32%) had one eligible vector. Three tests could not be analyzed due to prominent artifacts from the LVAD and were considered negative.

### 3.3 | Device-device interferences

Fourteen out of 80 patients (18%) identified as eligible for S-ICD implantation using the standard ECG-based screening test, had a negative device-based screening test. Using the device-based screening test, 73 patients (64%) were eligible for S-ICD implantation. Sixty-seven patients (53%) had ≥2 eligible vectors and 12 patients (11%) had one eligible vector. Sixty-six patients (57%) were found eligible for S-ICD therapy with both screening methods. Twenty-eight patients (24%) were found ineligible for S-ICD therapy with both screening methods.

**FIGURE 1** Exemplary S-ICD screening ECGs obtained from patients implanted with three different LVAD types (HeartMate II, HeartMate 3, and HVAD). Lead III represents the primary vector, lead II the secondary vector, and lead I the alternate vector. ECGs shown with HeartMate 3 and HVAD present high-frequency artifacts induced by the LVAD device. ECG, electrocardiogram; LVAD, left ventricular assist device; S-ICD, subcutaneous implantable cardioverter-defibrillator
3.4 | Reasons for failure of S-ICD screening tests

With the ECG-based screening test, a cumulative amount of 4.140 ECG tracings in all patients and all configurations (primary, secondary, and alternate vector; left and right parasternal position; three different gains) were analyzed. Out of these, 3.232 ECG tracings (78%) failed. Performing the device-based screening test, 2.760 S-ICD ECG tracings in all patients in all configurations (primary, secondary, and alternate vector; left and right parasternal position; two different gains) were registered, from which 1.733 tracings (63%) failed. Reasons for failure with both screening methods are presented in Table 3. All 14 patients (12%) found eligible with the

**TABLE 1** Baseline patient characteristics ($n = 115$)

| Parameter                        | $n = 115$ |
|----------------------------------|-----------|
| Age (years)                      | 58.5 ± 9.5|
| Male ($n$, %)                    | 95 (83)   |
| Chest circumference (cm)         | 107.3 ± 13.0|
| Body mass index (kg/m²)          | 28.3 ± 5.7|
| Underlying cardiomyopathy ($n$, %) |           |
| Dilated cardiomyopathy           | 70 (61)   |
| Ischemic cardiomyopathy          | 36 (31)   |
| Other                            | 9 (8)     |
| Prior cardiac surgery ($n$, %)   | 92 (80)   |
| Pacemaker dependent ($n$, %)     | 11 (10)   |
| LVAD type ($n$, %)               |           |
| HVAD                             | 73 (64)   |
| HeartMate II                     | 19 (16)   |
| HeartMate 3                      | 18 (16)   |
| Other (aVAD, HeartAssist5, MVAD) | 5 (4)     |
| Minimal invasive operation technique ($n$, %) | 53 (46) |

Abbreviation: LVAD, left ventricular assist device.

**TABLE 2** ECG parameters from 112 patients with left ventricular assist device

| Parameter                        | $n = 112$ |
|----------------------------------|-----------|
| Atrial rhythm ($n$, %)           |           |
| Sinus rhythm                     | 66 (59)   |
| Atrial fibrillation              | 19 (17)   |
| Paced                            | 27 (24)   |
| Heart rate (bpm)                 | 76.2 ± 16.1|
| Cardiac axis (°)                 | −27.5 ± 93.9|
| PR interval (ms)                 | 182.1 ± 51.5|
| QRS duration (ms)                | 131.3 ± 39.2|
| QRS morphology ($n$, %)          |           |
| QRS duration <120 ms             | 44 (39)   |
| LBBB                             | 18 (16)   |
| IVCD                             | 12 (11)   |
| RBBB                             | 11 (10)   |
| Paced                            | 27 (24)   |
| QTc interval (ms)                | 489.3 ± 60.3|

Abbreviations: IVCD, intraventricular conduction delay; LBBB, left bundle branch block; RBBB, right bundle branch block.
standard ECG-based screening test but ineligible with the device-based screening test, failed the device-based screening test due to either R wave undersensing \( (n = 10) \) or oversensing \( (n = 4) \) attributed to EMI (Figure 4).

**4 | DISCUSSION**

In the present study, 115 patients with an implanted LVAD were evaluated for S-ICD eligibility with the standard ECG-based screening test. S-ICD eligibility was further studied using a novel device-based screening test aimed at incorporating potential device-device interferences between LVAD and S-ICD into the S-ICD screening procedure.

The main findings of the present study are:

1. Eighty patients (70%) were eligible for S-ICD implantation with the standard ECG-based screening test.
2. Further evaluation of these patients eligible for S-ICD utilizing the device-based screening method identified 14 patients (18%) with device-device interference.

S-ICD therapy can be an alternative to transvenous ICD systems in patients with LVAD, since device-related infections and lead failures pose major challenges in these patients. Nevertheless, there have been several reports of device-device interference between LVADs and conventional ICD systems\(^\text{12,13}\) as well as inappropriate S-ICD sensing after LVAD implantation in S-ICD carriers leading to inappropriate ICD therapy.\(^\text{9,14,15}\) Thus, awareness and caution in the setting of coexistence of LVAD and S-ICD was raised.

Even though the ECG-based screening test is well established in clinical routine,\(^\text{16}\) it has not been extensively tested in patients with LVAD. The novel device-based screening method, which was described for the first time in the present study, attempts to imitate an implanted S-ICD system approximating device position to unmask potential S-ICD sensing failure and/or signal artifacts generated from the LVAD. Using this screening test, 14 out of the 80 assumed S-ICD eligible patients (18%) were found ineligible for S-ICD implantation with the device-based screening test. This finding suggests that S-ICD implantation in these cases, although considered feasible in clinical routine, may have led to S-ICD sensing failure and inappropriate ICD therapy, as reported before in patients after LVAD implantation.\(^\text{9,14,15}\) These 14 patients failed the device-based screening test due to R wave undersensing \( (n = 10) \) or oversensing \( (n = 4) \) unmasking device-device interference.

This additional novel device-based screening could be used in clinical routine if S-ICD implantation is planned in patients with

**TABLE 3** Reasons for S-ICD screening failure of all failed ECG-based \( (n = 3.232) \) and all failed device-based \( (n = 1.733) \) test tracings obtained during the screening test procedures

| Reasons for screening failure               | ECG-based test tracings \( (n = 3.232) \) | Device-based test tracings \( (n = 1.733) \) |
|--------------------------------------------|------------------------------------------|--------------------------------------------|
| Low amplitude QRS complex/R wave undersensing \( (n, \%) \) | 1.694 (52) | 1.482 (85) |
| T wave oversensing \( (n, \%) \) | 940 (29) | 98 (6) |
| High amplitude QRS complex \( (n, \%) \) | 556 (17) | - |
| Oversensing of the next P wave \( (n, \%) \) | 29 (1) | - |
| Broad QRS complex \( (n, \%) \) | 13 (1) | - |
| Oversensing due to EMI \( (n, \%) \) | - | 153 (9) |

Abbreviations: ECG, electrocardiogram; EMI, electromagnetic interference; S-ICD, subcutaneous implantable cardioverter-defibrillator.
LVAD to identify patients at risk for interactions between S-ICD and LVAD.

In the present study, S-ICD eligibility was found in 80 patients (70%) with LVAD using the standard ECG-based screening test, suggesting that an S-ICD could be safely implanted in these patients. A recent study in 75 patients with LVAD evaluated S-ICD eligibility utilizing both the ECG-based screening test and the automated screening test using the manufacturer’s programmer. With the ECG-based screening test higher eligibility rates (66.6%), similar to those found in the present study, were observed. Thus, S-ICD eligibility in patients with LVAD is lower in comparison to patients with heart failure without an LVAD.

In the present study, 66 patients (57%) were found eligible for S-ICD therapy using both screening methods. In case S-ICD therapy is considered in patients with LVAD, both the ECG-based and the device-based screening test should be positive to minimize the risk of potential device-device interference between the LVAD and the S-ICD.

Prospective studies evaluating S-ICD eligibility before and after LVAD implantation could further elucidate whether the observed ECG changes after LVAD implantation have an impact on S-ICD eligibility in patients with LVAD. Moreover, the novel device-based screening test should be further studied to evaluate its performance to identify eligible patients for S-ICD implantation.

4.1 Limitations

Patients with LVAD were screened for S-ICD eligibility, but did not receive an S-ICD. Thus, it is unclear if patients considered eligible for S-ICD show appropriate S-ICD sensing when implanted and vice versa.

In the present study, a novel device-based screening test was additionally performed. The chosen method does not represent an established tool in clinical practice and its sensitivity and specificity need to be further studied. However, the device-based screening test offers important information on potential EMI between LVAD and S-ICD. Finally, the costs of the required S-ICD device as well as the electrode are a limiting factor in the wide use of this screening tool.
4.2 Conclusion

Utilizing a novel device-based S-ICD screening method in patients with LVAD helped to identify patients with device-device interferences that were otherwise found eligible for S-ICD with the standard ECG-based screening test. In case of patients with LVAD considered for S-ICD implantation, careful S-ICD screening should be performed including the device-based screening test, first described in the present study.

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