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Infection in patients with subcutaneous implantable cardioverter-defibrillator: Results of the S-ICD Post Approval Study

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BACKGROUND Early subcutaneous implantable cardioverter-defibrillator (S-ICD) studies included atypical cohorts of patients who were younger with fewer comorbidities. Recent S-ICD studies included patient populations with more comorbidities.

OBJECTIVES The goals of this study were to determine the incidence and predictors of S-ICD–related infection over a 3-year follow-up period and to use these results to develop an infection risk score.

METHODS The S-ICD Post Approval Study is a US prospective registry of 1637 patients. Baseline demographic characteristics and outcomes with 3-year postimplantation follow-up were compared between patients with and without device-related infection. A risk score was derived from multivariable proportional hazards analysis of 22 variables.

RESULTS Infection was observed in 55 patients (3.3%), with 69% of infections occurring within 90 days and a vast majority (92.7%) within 1 year of implantation. Late infections more likely involved device erosion; no infections occurred after year 2. The annual mortality rate postinfection was 0.6%/y. No lead extraction complications or bacteremia related to infection were observed. An infection risk score was created with diabetes, age, prior transvenous ICD implant, and ejection fraction as predictors. Patients with a risk score of $\geq$3 had an 8.8 hazard ratio (95% confidence interval 2.8–16.3) of infection compared with a 0 risk score.

CONCLUSION Infection rates in the S-ICD Post Approval Study were similar to other S-ICD populations and not associated with systemic blood-borne infections. Late infection (>1 year) is uncommon and associated with system erosion. A high-risk infection cohort can be identified that may facilitate preventive measures.

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KEYWORDS Implantable cardioverter-defibrillator; Infection; Subcutaneous ICD; Risk score; Erosion

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Introduction

The subcutaneous implantable cardioverter-defibrillator (S-ICD) is available worldwide for the prevention of sudden cardiac death, with >100,000 devices implanted.[1] The S-ICD has no intravascular components and has demonstrated safety and efficacy for treating ventricular tachyarrhythmias.[2–6] One of the primary advantages of this device is to minimize the risk of lead complications including systemic infections. Early studies showed a low lead failure rate compared to transvenous devices. Although infections still occur at similar rates, bacteremia did not occur.[4–9] One-year transvenous ICD (TV-ICD) infection rates have ranged from 0.5% to 1.2%.[10–12] Despite the well-studied predictors of TV-ICD infections,[11–16] no such analysis has been performed for the S-ICD.

Although previous studies validated the efficacy and safety of S-ICD, the patient population was often atypical for ICD cohorts, with subjects being younger with fewer comorbidities.[2,4,5,8,9] Moreover, follow-up durations were often short. The more recent S-ICD Post Approval Study (S-ICD PAS),[7,17] Prospective, RAndomizEd comparison of subcuTaneOus and tRansvenous ImplANtable cardioverter-defibrillator therapy (PRAETORIAN),[6] and UNdersTanding OUtcomes With the S-ICD in Primary Prevention Patients With Low Ejection Fraction[3,18] trials are more typical of traditional ICD cohorts and thus represent more relevant populations to assess efficacy and risks. In this regard, S-ICD PAS was a prospective US registry of this device, with long-term follow-up prospectively planned.[7,17] The present report is an analysis of infections during the first 3 years of this trial, with a risk score to help identify a high-risk cohort to inform patient management decisions including infection preventive measures.

Methods

S-ICD PAS is a prospective registry with 1637 *de novo* patients enrolled across 86 US centers (ClincalTrials.gov Identifier NCT01736618), which was mandated by the Food and Drug Administration after device approval. Enrollment demographic details were published previously.[17] The protocol was approved by local institutional review boards before use. The study was conducted in accordance with applicable postmarket guidelines and the Declaration of Helsinki as revised in 2013. Patients eligible for S-ICD underwent a manual electrocardiogram screening test and underwent implantation from August 2013 until May 2016. Data up to 3 years post-implantation were used for this analysis.

Complications were defined as adverse events related to the implant procedure or the device, resulting in permanent loss of device function, invasive intervention, or death. All complications were verified by an independent clinical events committee. Any patient whose S-ICD was removed and not replaced with another S-ICD was removed from the study at the time of explantation. For this analysis, patients were stratified into 2 groups: those who had an infection complication or those with no infection complication. Patients with erosion complications were evaluated to determine whether infections were also involved as the root cause is often uncertain (infection or erosion). Accordingly, if concomitant infections were present with erosion, then patients with those infections were included into the infection complication group. Patients were censored at study discontinuation date to evaluate repeat infection occurrence. Patient mortality was assessed in (1) patients with a previous TV-ICD extracted owing to infection and (2) patients with infection.

Statistical analysis

Basic characteristics were analyzed using descriptive statistics. Kaplan-Meier analysis was performed by censoring subjects at their last known status. Proportional hazards analysis was used to calculate hazard ratios (HRs), 95% confidence intervals, and Wald χ^2 P values. For proportional hazards analysis, all variables of interest were entered into the model, followed by stepwise selection criteria with a P value of .2 to enter the model and .2 to remain in the model.

An infection risk score model was developed on the basis of the multivariable predictors, excluding predictors with >5% missing values. Backward model selection was performed with $\alpha = 5\%$ using a proportional hazards model. Risk score development was performed with 1000 bootstrap data sets (see Online Supplemental Figure 1). The bootstrapping method was used to avoid data overfitting in risk model development.[19] Subjects not selected for a given bootstrap development data set were used for risk score validation. On average, the development set included 65% of patients, with the validation set including the remaining 35%. Logistic regression was performed on continuous variables and receiver operating characteristic curve analysis was used to identify the optimal threshold point across all bootstrap samples. A multivariable proportional hazards model was run using the bootstrap samples and resulting threshold points to find the median variable β for each predictor. Integer risk scores were assigned on the basis of β variables. Risk scores were combined for small patient cohorts.

All statistical analyses were performed using SAS version 9.4 (SAS Institute, Cary, NC). A P value of <.05 was considered statistically significant.

Results

Within 3 years of implantation, 55 patients (3.4%) had an infection. There were no reported deaths attributed to infection or subsequent S-ICD pulse generator (PG) and/or electrode removal. No patient had >1 infection. Of the 55 patients with an infection, 45 (81.8%) had S-ICD system–related infections with the PG explanted in all cases, 4 (7.3%) patients had an infection classified as superficial infection involving intervention but no device removal, and 6 (10.9%) remaining patients had an infection associated with electrode or PG erosion. For these 6 patients, the PG

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Table 1 Subject demographic characteristics and procedural outcomes

Characteristic	Infection (n = 55[3.4%])	No infection(n = 1582 [96.6%])	*P*
Age (y)			.27
Mean ± SD (median)	51 ± 14(51)	53 ± 15(55)	
Range	19–80	15–89	
Male	36/55(65.5)	1086/1582(68.6)	.62
Body mass index (kg/m^2)			.03
N	55	1578	
Mean ± SD (median)	32 ± 8 (31)	30 ± 8 (28)	
Range	16–53	9–101	
Primary prevention	42/55 (76.4)	1212/1582 (76.6)	.97
LVEF (%)			.12
N	55	1538	
Mean ± SD (median)	29 ± 14(27)	32 ± 15(30)	
Range	5–65	5–85	
NYHA HF class III–IV	15/47(31.9)	382/1349(28.3)	.59
Diabetes	27/55(49.1)	524/1582(33.1)	.01
Prior TV-ICD implant	20/55(36.4)	191/1582(12.1)	<.0001
Prior TV-ICD implant, explanted owing to infection	14/55(25.5)	97/1582(6.1)	<.0001[†]
Dialysis	7/55(12.7)	213/1582(13.5)	.87
Oral anticoagulant	15/55(27.3)	412/1582(26.0)	.84
Procedure time (min)			.03
N	55	1560	
Mean ± SD (median)	88 ± 40(82)	77 ± 36(69)	
Range	25–199	2–280	
Length of stay (d)			.67[‡]
N	55	1582	
Mean ± SD (median)	3 ± 5(1)	3 ± 6(1)	
Range	0–28	0–73	
Inpatient procedure	8/55(14.5)	304/1582(19.2)	.39
Prophylactic antibiotics given	53/54(98.1)	1516/1551 (97.7)	1.00
PG implanted in the subcutaneous location	52/55(94.5)	138/1579 (91.3)	.62
2 Incision implantation method	28/54 (51.9)	825/1581 (52.2)	.96
General anesthesia	34/55 (61.8)	1015/1581 (64.2)	.72
Conscious sedation	21/55 (38.2)	564/1581 (35.7)	
Local anesthesia	0/55 (0.0)	2/1581 (0.1)	
Hematoma	4/55 (7.3)	29/1582 (1.8)	.02
Experience variables			
IDE center	23/55 (41.8)	666/1582 (42.1)	.97
Implant number			.12
N	55	1582	
Mean ± SD (median)	15 ± 15 (12)	17 ± 15 (13)	
Range	1–73	1–86	
Implant tertile			.53
1	23/55 (41.8)	570/1582 (36.0)	
2	18/55 (32.7)	503/1582 (31.8)	
3	14/55 (25.5)	509/1582 (32.2)	
Implant year			.87
2013	4/55 (7.3)	80/1582 (5.1)	
2014	13/55 (23.6)	366/1582 (23.1)	
2015	25/55 (45.5)	782/1582 (49.4)	
2016	13/55 (23.6)	354/1582 (22.4)	

Values are presented as n/total n (%) unless otherwise indicated.

HF = heart failure; IDE = investigational device exemption; LVEF = left ventricular ejection fraction; NYHA = New York Heart Association; PG = pulse generator; TV-ICD = transvenous implantable cardioverter-defibrillator.

[†]*P* value calculated using the Fisher exact test.

[‡]*P* value calculated using the Kruskal-Wallis test.

was explanted in 5 (9.1%) patients. In the sixth patient, electrode erosion occurred with the lead removed while the PG remained implanted. Thus, of the 55 patients who had an infection, 50 (90.9%) had their PG explanted (Online Supplemental Table 1) and 2 of these (3.6%) had an S-ICD replacement.

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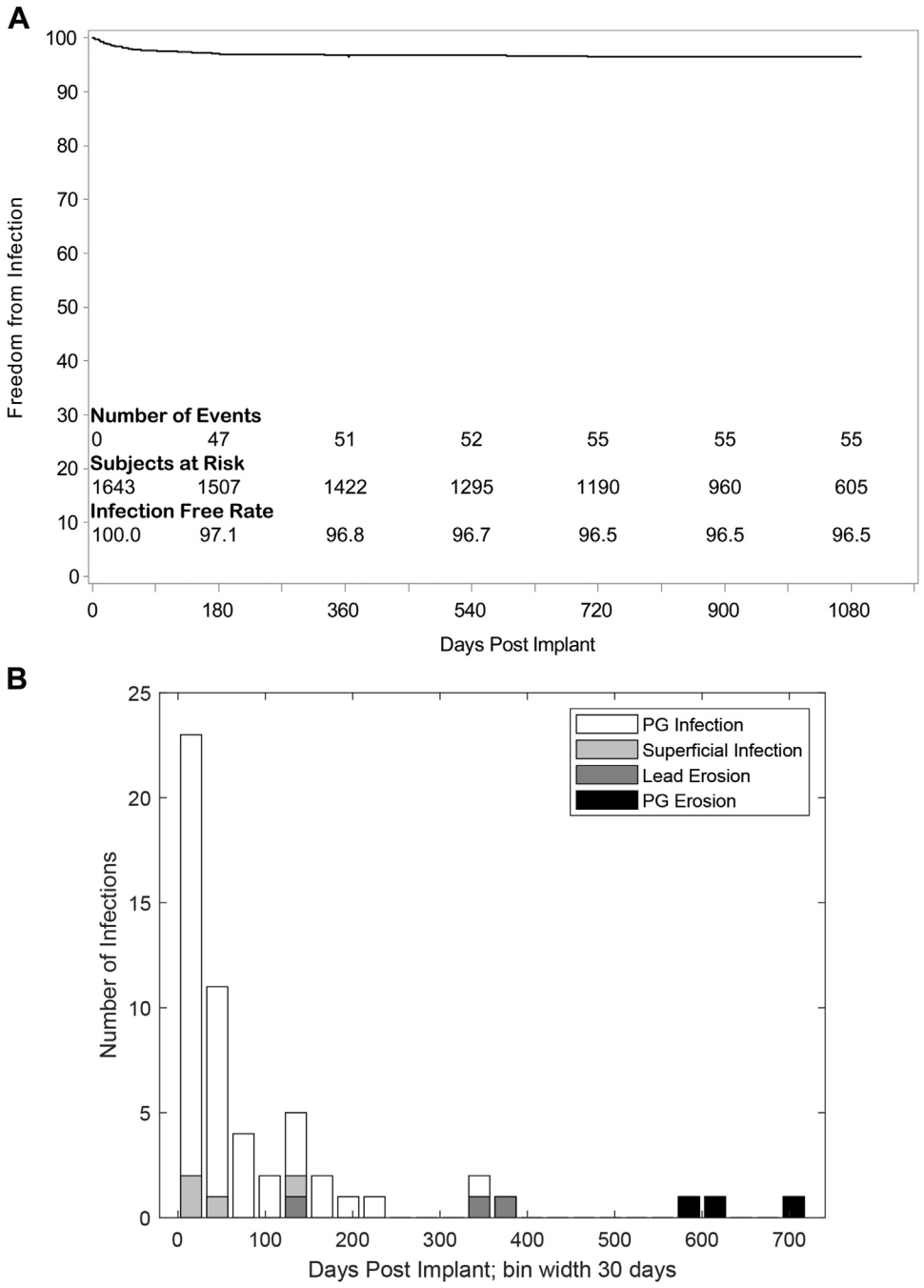

Figure 1 **A:** Kaplan-Meier analysis of infections. **B:** Infection date postimplantation by infection type. PG = pulse generator.

Baseline demographic and procedural characteristics

Baseline demographic and procedural characteristic comparisons are presented in Table 1. Patients with infection were younger, had a higher body mass index, and were more likely to have diabetes ($P = .01$). Importantly, severity of heart failure, dialysis, and oral anticoagulation use did not affect infection risk.

From a procedural perspective, prior transvenous defibrillator implant ($P < .0001$) was associated with infection. Longer procedure time and hematoma complicating implant surgery were also associated with infection. Patients with a prior TV-ICD explanted because of infection leading to S-ICD implantation did not have a higher mortality rate than did the rest of the study cohort (12.6% [14 of 111] vs 11.1% [170 of 1526]; $P = .64$).

Because of the observational nature of S-ICD PAS, evaluation of systemic infection and documentation of culture results and antibiotic treatment were not required and thus not routinely collected, so these results should be interpreted with caution. In the 18 patients for whom culture results (wound or unspecified) were recorded, most infections were due to

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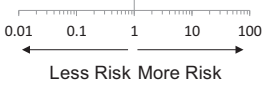
A

Variable	Hazard Ratio	P-value
Procedure Time (mins)*	1.01 (1.00-1.01)	.028
2 Incision	0.99 (0.58-1.69)	.97
Oral Anticoagulant	1.09 (0.60-1.98)	.77
Diabetes	1.96 (1.16-3.33)	.013
Body Mass Index (kg/m^2)*	1.03 (1.01-1.06)	.019
Age at Implant (years)*	0.99 (0.97-1.01)	.28
Primary Prevention Indication	0.97 (0.52-1.80)	.92
Length of stay (days)*	1.00 (0.95-1.05)	.88
Hematoma prior to infection	4.23 (1.53-11.71)	.0055
General Anesthesia	0.91 (0.53-1.57)	.73
Conscious Anesthesia	1.11 (0.64-1.91)	.71
Dialysis	0.98 (0.44-2.16)	.95
In Patient	0.70 (0.33-1.49)	.36
Prior TV-ICD	4.03 (2.33-6.98)	<.0001
Prior TV-ICD extracted due to infection	5.01 (2.73-9.19)	<.0001
IDE Center †	0.99 (0.58-1.69)	.97
Implant Number* †	0.99 (0.97-1.01)	.27
Tertile of Implant Order* †	0.83 (0.60-1.15)	.25
Implant Year* †	0.94 (0.68-1.30)	.71
Race - White	0.74 (0.43-1.25)	.25
NYHA Class III or IV	1.23 (0.67-2.27)	.51
LVEF*	0.98 (0.96-1.00)	.12



B

Variable	Hazard Ratio	P-value
Diabetes	1.905 (1.096-3.308)	.022
Age at Implant (years)*	0.978 (0.959-0.997)	.021
Prior TV-ICD	4.836 (2.766-8.453)	<.0001
LVEF*	0.978 (0.958-0.999)	.038

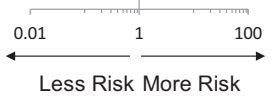


Figure 2 **A:** Univariable predictors of infection. **B:** Multivariable predictors of infection. IDE = investigational device exemption; LVEF = left ventricular ejection fraction; NYHA = New York Heart Association; TV-ICD = transvenous implantable cardioverter-defibrillator. * continuous variable; † variables to evaluate implant experience.

Staphylococcus species (Online Supplemental Table 2), with 66.7% of patients showing either unspecified *Staphylococcus* (6 of 18 [33.3%]), methicillin-resistant *S aureus* (5 of 18 [27.8%]), or methicillin-sensitive *S aureus* (1 of 18 [5.6%]). Only 2 of 18 patients (11.1%) had documented blood culture results, who both showed no bacteremia. Of the 55 patients who had an infection, 1 patient died (1.8%). In contrast, the noninfection cohort had 11.2% deaths (183 of 1582), which was a significantly higher death rate (P = .024). The 1 patient in the infection cohort who died had a history of heart failure (New York Heart Association class III/IV) and kidney failure. Fifteen days postimplantation, the patient's device was explanted because of a recurring hematoma and infection; the latter was confirmed by wound culture results. The patient chose comfort care and died 28 days after device implant, with the cause of death reported as worsening heart and kidney failure.

Incidence and timing

Kaplan-Meier analysis of infection complication occurrence over 3 years after S-ICD implantation is shown in Figure 1A. Most infections occurred within the first 180 days (47 of 55 [85.4%]). Of the remaining 8 (14.5%) infections, 4 (7.3%)

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Table 2 Median β values from proportional hazards model and resulting risk scores for each predictor

Predictor	Median β values	Components of the risk score
Diabetes	0.64	1
Age ≤ 55 y	0.70	1
Previous ICD implant	1.59	2
LVEF ≤ 30%	0.75	1

ICD = implantable cardioverter-defibrillator; LVEF = left ventricular ejection fraction.

occurred within the first year of implant and the remaining 4 (7.3%) occurred between years 1 and 2. No infections were reported between years 2 and 3. The 4 infections without device removal and not associated with erosion occurred within 125 days of implantation. All 45 (81.8%) infections requiring device removal that did not involve erosion occurred within the first year of implant. The 3 (5.5%) infections involving lead erosion occurred 124, 331, and 372 days postimplantation, whereas the 3 (5.5%) infections involving PG erosion occurred between year 1 and year 2 postimplantation (Figure 1B).

Infection predictors

Multivariable proportional hazards analysis was performed to evaluate patient- and procedure-related characteristics associated with S-ICD-related infection over 3 years. Univariable and multivariable logistic regression analysis results are shown in Figures 2A and 2B, respectively. None of the indicators of implantation experience (investigational device exemption center, implant number, implant order tertile, and implant year) were significant univariable or multivariable predictors of S-ICD-related infection. Significant multivariable infection predictors were diabetes (HR 1.91; P = .022), younger age (HR 0.98; P = .021), prior TV-ICD implant (HR 4.84; P < .0001), and lower left ventricular ejection fraction (LVEF) (HR 0.98; P = .038). It is noteworthy that although dialysis was included in the model, on the basis of previous studies indicating it as a risk factor for cardiovascular implantable electronic device infections,[12,13] it was not a significant independent predictor of S-ICD-related infection.

A risk factor model was developed on the basis of the multivariable infection predictors and identified their risk score coefficients (Table 2). The distribution of risk scores for 1593 of 1637 patients (97.3%) in the S-ICD PAS study is illustrated in Figure 3A. Risk scores 3–5 were combined as they represented only 18.9% of patients. Kaplan-Meier estimates by risk scores are presented in Figure 3B for all S-ICD PAS patients. The 3-year Kaplan-Meier estimates for the test data set, the validation data set, and the entire cohort were similar (Online Supplemental Figure 2). Figure 3C illustrates the HRs and 95% confidence intervals for risk scores 1, 2, and 3–5, compared with a risk score of 0. For all data sets, the 95% confidence intervals for risk scores 1 and 2 span unity whereas the HR for risk scores ≥ 3 was 8.8.

Discussion

The present study used the largest S-ICD prospective study to date. While infection was not the primary end point of S-ICD PAS, the registry allowed assessment of risk. Moreover, this is the first report to evaluate clinical predictors of S-ICD-related infection. We evaluated the incidence of all infections reported as complications (requiring invasive intervention), including superficial infections and infections associated with erosions.[15,16] This broad criteria for inclusion was chosen to prevent underestimating infection risk and to report on infection complications that may not require S-ICD extraction.

We report several important findings. First, infection occurred in 3.3% of patients (55), with the vast majority occurring in the first year postimplantation. Furthermore, no patient had >1 infection during 3-year follow-up. Second, all infections occurring after the first year postimplantation were associated with lead or PG erosion. Moreover, no patient had an infection after the second year postimplantation. Third, implantation duration, hematoma, and system revision were all univariable predictors of infection, similar to predictors from TV-ICD studies.[12,16,20,21] However, dialysis was not a predictor for infection, presumably because transient bacteremia is unlikely to contaminate the S-ICD system. Fourth, a risk score was developed to predict infection that was strongly predictive of events. Specifically, a risk score of ≥3 (range 0–5) was associated with 8.8 times increased infection risk vs a risk score of 0.

Infection incidence has been evaluated in other S-ICD patient cohorts. In the investigational device exemption study, the infection rate requiring explanation was 1.2% at follow-up of ∼1 year.[5] In the Dutch cohort it was 5.1% at 1 year,[4] whereas in the Evaluation oF FactORs ImpacTing CLinical Outcome and Cost EffectiveneSS of the S-ICD registry it was 2.3%.[2] Thus, the 3.2% 1-year infection rate (2.7% for infections requiring device explantation) in the present study is within the range noted previously, despite a cohort with more comorbidities including heart failure, cardiomyopathy, and diabetes. In support of this finding, the UNderstanding OUtcomes With the S-ICD in Primary Prevention Patients With Low Ejection Fraction study of primary prevention patients with a reduced ejection fraction reported an infection rate of 1.1% in 18 months with device explantation and an overall infection rate of 1.5% in 18 months.[3] The PRAETORIAN trial reported a low annual (0.2%) infection rate with only 4 (0.9%) infections over 48 months in the S-ICD cohort (n = 426).[6] Thus, the more contemporary cohorts of sicker and somewhat older patients were not associated with an increased infection risk. This may be due to improved implantation techniques, smaller devices, or more experienced implanters.

This study identified 4 risk factors of S-ICD-related infection: patients with a previous ICD implant (extracted for any

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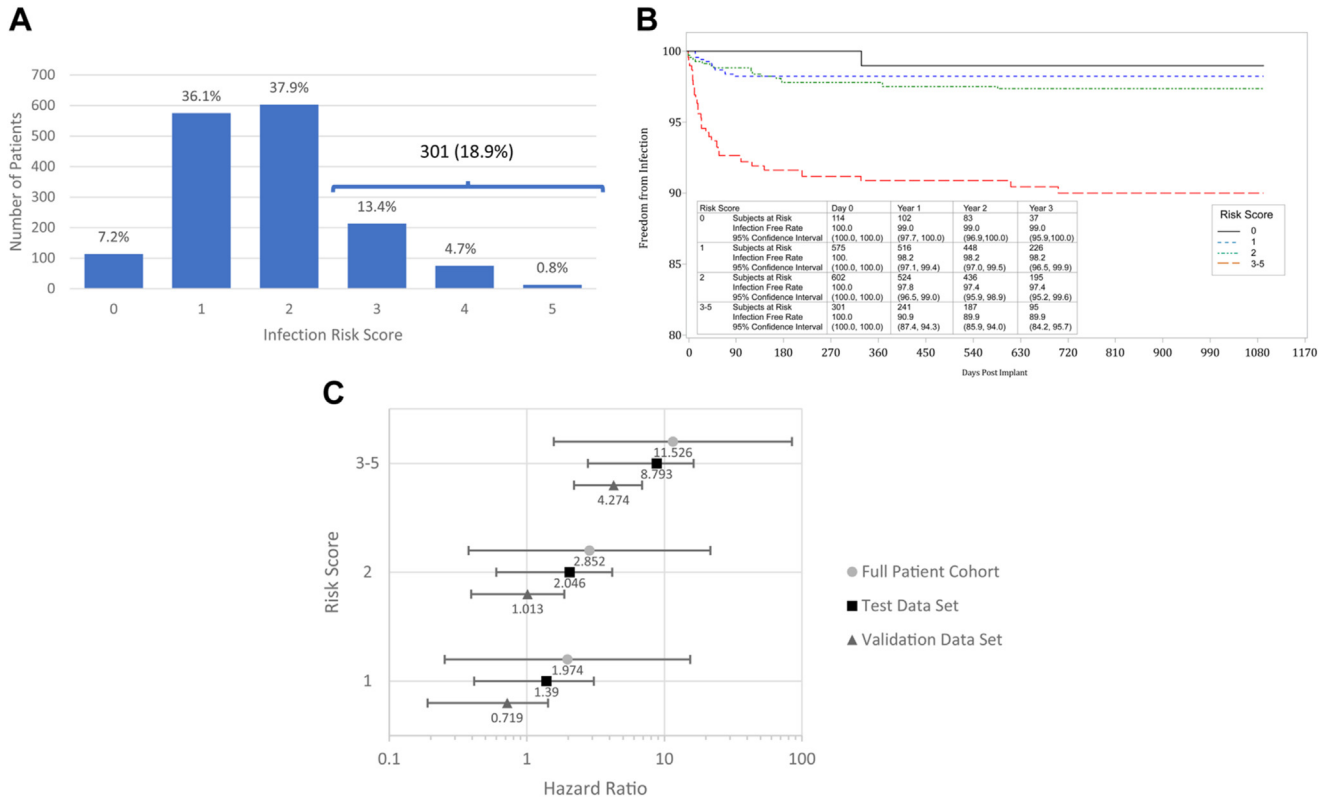

Figure 3 **A:** Risk score distribution for patients in the S-ICD Post Approval Study; 44 patients had missing information for ≥1 predictors. **B:** Kaplan-Meier estimates by risk score. **C:** Hazard ratios for each risk score across the entire population.

reason), age ≤ 55 years, LVEF ≤ 30%, and patients with diabetes. Patients with a risk score of ≥3 have an infection risk 8.8 times higher than patients with a risk score of 0. Similarly, TV-ICD infection risk models showed that prior transvenous device replacement/revision/upgrade procedures increase infection risk.[11,13,21] In contrast, 1 study showed that S-ICD recipients with a previous TV-ICD did not have an increased infection risk.[22] The present study includes sicker patients and longer follow-up, which could explain this discrepancy. Younger age was found to be a risk factor in 2 transvenous device infection studies,[11,12,23] with previously speculated reasons being changes in immune response and subcutaneous tissue firmness that occur with age.[11,23] Whereas LVEF was not part of TV-ICD infection risk models, heart failure was included in 3 studies[11,13,21] but prevailed in the risk model in only 1 study.[13] Presumably, heart failure or low LVEF did not prevail in other risk models, as they covary with other variables such as type of device implant and number of previous procedures. Diabetes was also included in TV-ICD infection risk models.[11–13,21]

The present report describes infection incidence from implantation years 2013–2016, which is relatively early in the S-ICD experience. However, it is noteworthy that no implant experience variables were associated with infection (Figure 2A).

Several studies have compared S-ICD- and TV-ICD-related infection rates,[24–30] including 2 prospective randomized studies.[6,31] The PRAETORIAN trial showed 0.9% S-ICD-related infection compared with 1.9% TV-

Table 3 S-ICD- and TV-ICD-related infection rates, year 1 and after year 1

First author, year, reference	Study/type	Device type(s)	% SC	No. of patients	Follow-up duration (y)	Overall infection rate (%)	Infection rate at year 1 (%)	Infections per year after year 1 (%)
Brouwer et al (2016)[27]	Netherlands 2 high-volume centers; propensity matched	S-ICD	N/A	140	5	4.10	3.00	0.28
		TV-ICD	11.40	140	5	3.60	0.00	0.9
Palmisano et al (2021)[26]	POINTED registry; propensity matched	S-ICD	N/A	169	2.5	0.60	0.60	0.00
		TV-ICD	81.70	169	2.5	1.20	0.60	0.40
Boersma et al (2017)[2]	EFFORLTESS S-ICD registry	S-ICD	N/A	984	3	2.30	2.3	0.00
Quast et al (2018)[4]	Dutch Cohort S-ICD registry	S-ICD	N/A	118	6.1	6.80	5.1	0.33

EFFORLTESS = Evaluation oF FactORs ImpacTing CLinical Outcome and Cost EffectiveneSS of the S-ICD; N/A = not available; POINTED = Impact on Patient Outcome of Cardiac ImplaNTable Electronic Device Complications; SC = single chamber; S-ICD = subcutaneous implantable cardioverter-defibrillator; TV-ICD = transvenous implantable cardioverter-defibrillator.

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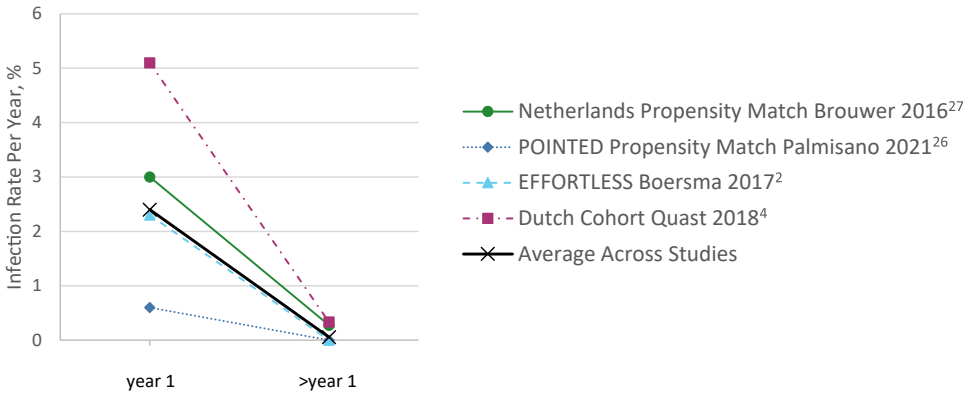

Figure 4 S-ICD-related infection rates per year, first year postimplantation vs subsequent years. Note: this graph plots the S-ICD data in Table 3 columns "Infection rate year 1 (%)" and "Infections per year after year 1 (%). EFFORTLESS = Evaluation oF FactORs ImpacTing CLinical Outcome and Cost EffectiveneSS of the S-ICD; POINTED = Impact on Patient Outcome of Cardiac ImplaNTable Electronic Device Complications; S-ICD = subcutaneous implantable cardioverter-defibrillator.

ICD-related infection at 4-year follow-up.[6] Recently, the Avoid Transvenous Leads in Appropriate Subjects trial reported 2 S-ICD-related infections (0.8%) compared with 1 TV-ICD-related infection (0.4%) at 6-month follow-up.[31] No study to date has shown a significant difference in device-related infection between patients with S-ICD and those with TV-ICD.

Table 3 summarizes S-ICD-related infection rates from studies reporting infections beyond 1 year, including 2 studies with S-ICD and TV-ICD propensity score–matched data. S-ICD-related infection rates are also shown graphically in Figure 4. The annual S-ICD infection rates after year 1 are considerably lower than rates at year 1; indeed, 2 studies reported 0 infections after year 1.[2,26] Infection rates after 1 year implantation appear considerably lower in patients implanted with the S-ICD than in those with TV-ICD, presumably because of the markedly decreased risk of blood-borne infections.

Infection rates were significantly decreased with an antibacterial envelope in transvenous device implantation.[10,32] While antibacterial envelope use has been recommended for transvenous device recipients at high infection risk,[33] it is unknown whether such measures would significantly impact S-ICD-related infection risk. Nevertheless, it is recommended that high-risk patients identified in this risk model be considered for such preventive measures.

Although overall infection rates may have no significant differences between device types, the consequences may be more severe with the TV-ICD, especially when undergoing transvenous replacements.[22,34] After TV-ICD explantation, S-ICD implantation mortality risk appears lower than that for TV-ICD reimplantaton. Boersma et al[22] reported a 3.6% mortality rate over 3 years post TV-ICD extraction for infection when an S-ICD has been reimplanted. The present study demonstrated no mortality difference between patients with a previous TV-ICD explant for infection compared with the rest of the S-ICD cohort. Indeed, the mortality rate of S-ICD PAS patients with an S-ICD-related infection was 0.6%/y, which was significantly lower than the mortality rate of 3.7%/y for noninfection S-ICD PAS patients. This low mortality after S-ICD reimplantation after device infection constrasts with TV-ICD reimplantation. A large single-center study reported a 10% mortality for pocket infections and a 32% mortality for endocarditis-related cardiovascular implantable electronic device infections over 3 years postextraction.[34] These studies showing outcomes managing TV-ICD infections with an S-ICD reimplantation are compelling, suggesting that such an approach should be considered for managing TV-ICD infections.

This study should be interpreted in light of certain limitations. S-ICD PAS was not specifically focused on infection rates. Thus, some parameters that might be significant predictors of infection were not collected. Second, microbiological data were not systematically collected and are incomplete. However, the data obtained showed that gram-positive organisms, particularly *Staphylococcus* species, were the dominant bacteria associated with infection, as expected. In addition, there was no predetermined treatment algorithm for infection; thus, this study represents a real-world experience vs a systematic approach to infection management. Furthermore, the risk score has not been externally validated. Finally, a variety of implantation techniques are used for S-ICD implants, so it is unclear which procedural aspects of implantation may have contributed to higher infection rates.

Conclusion

During 3 years of follow-up of S-ICD PAS, 3.3% of patients had a device infection, no patient had recurring infections, no patient had bacteremia, and patients who had a device infection did not have a higher mortality rate. An infection risk score was created for patients implanted with the S-ICD; patients with a risk score of $\geq$3 are 8.8 times as likely to have an infection as those with no comorbidities affecting infection: diabetes comorbidity, age $>$ 55 years, previous ICD implant, and LVEF $>$ 30%. Identifying high-risk subgroups may help to develop preventive strategies to reduce further infection with this device, such as antibiotics with a longer half-life

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or an antibacterial envelope. S-ICD implantation after TV-ICD infection is a viable approach that may be preferable to implanting another transvenous device.

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Appendix

Supplementary data

Supplementary data associated with this article can be found in the online version at https://doi.org/10.1016/j.hrthm.2022.07.031.

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