Characteristics and Outcomes in Patients With Electrical Storm

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Electrical storm (ES) is a life-threatening condition with diverse clinical presentation, caused by recurrent malignant ventricular arrhythmia−−≥3 episodes of ventricular tachycardia (VT) or ventricular fibrillation within 24 hours and is associated with high mortality. The aim of this study was analysis of clinical profile, treatment, and prognosis of patients with ES admitted to a high-volume cardiovascular center. We present results of a single-center, retrospective, ongoing observational registry enrolling consecutive patients presenting with ES admitted between 2006 and 2017. Clinical history, results of diagnostic investigations, and treatment were collected for all patients. Follow-up data were collected from hospital documentation, outpatient clinic, remote monitoring systems, and from data gathered from national health services. Registry enrolled 101 consecutive patients admitted with ES. Two-thirds of patients had ischemic cardiomyopathy. Mean left ventricle ejection fraction was 26%. In 56.4% of the patients coronary angiogram was performed and in 20.8% cases percutaneous coronary intervention was needed. 18.8% of the patients underwent VT ablation. 12-month mortality from first ES in our population was 21.8%. NYHA class III and IV, raised N-terminal fragment of prohormone B-type Natriuretic Peptide and creatinine levels, and lower hemoglobin levels were independent predictors of death. In conclusion, most patients admitted with ES have ischemic cardiomyopathy. Over 1/3 of the population had significant narrowing of at least one coronary artery with ES masking ischemia and underwent percutaneous coronary intervention. Nearly 1/5 of the patients were treated with VT ablation. 12-month mortality was high and exceeded 1/4 of patients with ES. **(Am J Cardiol 2019;123:1637−1642)**

The term "electrical storm" (ES) is defined as ≥3 episodes of sustained ventricular tachycardia (VT), ventricular fibrillation (VF) or appropriate shocks from implantable cardioverter-defibrillator (ICD) within 24 hours.[1,2] In primary prevention, incidence of ES reaches about 4%[3,4,5] and in secondary prevention 10% to 40%.[6,7,8] Prevalence of ES in resynchronization devices with cardioverter-defibrillator groups were significantly lower as compared with ICD.[5,9,10] ES remains a very serious aggravating factor with high long-term mortality.[8,11,12] It is proven, that ES strongly increases incidence of death, mainly secondary to heart failure (HF) worsening.[9,13,14] Revascularization is a successful technique when sustained polymorphic VT or VF in patients with coronary artery disease (CAD) is present. However, may be ineffective to prevent form recurrent monomorphic VT.[2,15] It is proved that VT ablation in patients with ES significantly decreases recurrence of ventricular arrhythmia (VA) and may prolong life in those ,patients.[14] There are lacking data from randomized trials dedicated to ES. Therefore, it seems that results from all-comers real-life registries lead by high-volume reference cardiology units would be an important source of clinical knowledge. The purpose of this study was the analysis of clinical profile, treatment, and prognosis of patients with ES admitted to a high-volume cardiovascular center.

Methods

Our registry is a single, high-volume cardiovascular center, retrospective, ongoing observational registry enrolling consecutive nonselected patients presenting with ES. The index hospitalization for each patient is the first admission to our center due to ES. Complete patient demographics, medical history, hospitalization data (diagnostic and therapeutic) and in-hospital results are collected in an electronic form by the attending physician. Total and 12-month mortality, and recurrence of ES was assessed on the basis of information achieved from National Health Service and data from hospital admissions caused by ES. The all-cause mortality data with the accompanying exact dates of deaths were obtained from the official national health found mortality records. The vital status at 12 months was available for all of the patients. The patients were treated according to the current (at the time of admission) European Society of Cardiology Heart Failure Treatment, Myocardial Revascularization, Cardiac Pacing and Cardiac Resynchronization Therapy guidelines. The study was granted exemption from review by the local ethics committee due to retrospective character of this study and a relevant written statement was obtained.

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Table 1
Baseline clinical characteristics of the patients hospitalized due to electrical storm

Variable	n = 101
Age (years)	62.0 ± 12.8
Men	86.1%
Ischemic etiology	72.2%
Secondary prevention	9.9%
NYHA class of heart failure at admission	
II	60%
III	26.3%
IV	13.8%
Infection at admission	14.3%
Acute coronary syndromes	4.0%
Arterial hypertension	59.4%
Stable coronary artery disease	52.0%
Previous myocardial infarction	60.4%
Previous PCI	52.4%
Previous CABG	14.5%
History of stroke and/or transient ischemic attack	7.1%
Atrial fibrillation or flutter	45.5%
Diabetes mellitus	34.7%
Hyperlipidemia	39.2%
Chronic kidney disease (class ≤3)	20.8%
Chronic obstructive pulmonary disease	9.9%
History of hyperthyroidism	11.9%
History of hypothyroidism	9.3%
Current smoking	9.4%
Type of cardiac implantable electronic device	
Single chamber ICD	23.3%
Dual chamber ICD	28.9%
CRT-D	47.8 %
No device	10.9%
White blood cells (10^{6}/ul)	9.2 ± 3.9
Red blood cells (10^{6}/ul)	4.5 ± 0.6
NT pro-BNP (pg/ml)	3017 ± 2345
Potassium (mmol/L)	4.18 ± 0.65
Thyroid stimulating hormone (mU/L)	1.95 ± 2.18

Hyperlipidemia defined as history of hyperlipidemia diagnosed and/or treated by physician, documentation of total cholesterol 200 mg/dl, low-density. Lipoprotein 130 mg/dl, high-density lipoprotein 30 mg/dl, admission cholesterol 200 mg/dl, or triglycerides 150 mg/dl.

CABG = coronary artery bypass grafting; CRT-D = cardiac resynchronization therapy with defibrillator; ICD = implantable cardioverter-defibrillator; NYHA = New York Heart Association; PCI = percutaneous coronary intervention.

In patients with diagnosis of acute coronary syndrome (ACS) according to current guidelines, any history of previous CAD and suspicion of ischemic background of ES (based on risk factors for CAD), coronary angiography (CA) was performed. ACS was diagnosed if all of following were present: typical chest pain and/or ischemic changes in electrocardiogram, regional contractility disturbances in echocardiogram with corresponding electrocardiogram changes and/or significant narrowing in coronary artery in CA. Percutaneous coronary intervention (PCI) was also indicated in patients without ACS, but with narrowing in coronary arteries assessed as significant by the operator. Some patients, in whom reversible causes of ES were not found, those after successful revascularization and recurrent VT/VF, with angiograms without any significant narrowing, or with nonischemic cardiomyopathy defined as impaired left ventricle function without underlying advanced CAD or previous myocardial infarction, were diverted for ablation once they clinical condition was stable. Decision regarding qualification for ablation and revascularization during index hospitalization was left to the discretion of an attending cardiologist. In 2 cases, because of a high risk of ablation, extracorporeal circulatory support was used during the procedure.

Table 2
Baseline echocardiographic and electrocardiographic parameters

Variable	n = 101
Left ventricle ejection fraction, (IR)	26.0% (12−46)
Patients with left ventricle ejection fraction <35	61.9%
Left ventricle end-diastolic volume, ml (IR)	220 (98−530)
Left ventricle end-systolic volume, ml (IR)	163 (55−440)
Severe mitral regurgitation	11.3%
Severe tricuspid regurgitation	6.2%
Severe aortic stenosis	1.01%
QRS complex duration, ms	135 ± 53
QT corrected interval duration, ms	456.6 ± 51.9

IR = interquartil range.

The main outcome measures were: recurrence of the ES and 12-month all-cause mortality.

Normality of variable distribution was confirmed using the Shapiro-Wilk test. Parameters of descriptive

Table 3
Electrical storm treatment during hospitalization

Variable	n = 101
Pharmacotherapy	
Beta-blocker	97.5%
Amiodarone	78.5%
Lignocaine	19.5%
Propafenon	10.2%
Magnesium	62.8%
Potasium	78.2%
Statins	65.8%
Angiotensin convertase inhibitor/angiotensin receptor blocker	78.2%
Loop diuretics	71.1%
Mineralocorticoid blocker	81.4%
Interventional/invasive treatment	
Coronarography	56.4%
Percutaneous coronary intervention	20.8%
Left main	10.5%*
Left anterior descending/diagonal branch	52.6%*
Circumflex/obtuse marginal branch	26.8%*
Right coronary artery	52.6%*
1 vessel CAD	38.1%*
2 vessel CAD	47.6%*
3 vessel CAD	14.3%*
CTO	33.3%*
Coronary stent implantation	18.8%
Coronarography/percutaneous coronary intervention ratio	36.8%
Ventricular tachycardia ablation	18.8%
Intra-aortic balloon pump	3%
External defibrillation	6.4%
Left ventricle assist device	2%
Cardiac implantable electronic device generator replacement	2%

CAD = coronary artery disease; CTO = chronic total occlusion.
* Refers to patients who underwent percutaneous coronary intervention.

statistics for continuous variables with a normal distribution are presented in the form of arithmetic mean and SD, and variables with a non-normal distribution—in the form of median and quartile range (interquartile range). Qualitative variables were presented as percentages. The analysis of survival in the 12-month observation was carried out using the Kaplan-Meier method. The prognostic relevance of the various baseline variables on the occurrence of death in the observation period was assessed with Cox proportional hazards regression models with results expressed as adjusted hazard ratios (HR) and 95% confidence intervals (CI). SAS software (version 9.4 SAS Institute, Cary, North Carolina) was used for statistical analyses.

Results

Data of 101 consecutive patients admitted to our center between 1st January 2009 and 31st March 2017 were analysed. The baseline clinical characteristic is presented in Table 1. Echocardiographic and electrocardiographic parameters at enrolment can be found in Table 2. Most patients had implemented standard treatment for HF (details in Table 3). In-hospital treatment including interventional procedures is described in Table 3. The trends of ES and invasive treatment rate during the study period are presented in Figure 1. The follow-up data with 12-month mortality reaching up to 22% (Figure 2) are available in Table 4.

The multivariate analysis revealed that NYHA class III or IV on admission (HR 8.53, 1.12 to 16.83, $p = 0.03$), raised levels of creatinine (HR 1.02, 1.004 to 1.04, $p = 0.02$), N-terminal fragment of prohormone B-type Natriuretic Peptide (HR 1.01, 1.001 to 1.05, $p = 0.03$) and decreased hemoglobin levels (HR 0.36, 0.15 to 0.87, $p = 0.02$) were independent predictors of 12-month mortality in the study population (Table 5).

Discussion

Our data are gathered from an all-comers real-life registry from a high-volume top reference center. According to our best knowledge, this is one of the biggest registries dedicated exclusively to patients with ES. Moreover, the data analyzed gather all noninvasive and invasive methods used and are not narrowed to strictly electrophysiological procedures, which seems to be important considering, that most of the patients with ES have ischemic cardiomyopathy. Patients enrolled to the registry are all consecutive and not selected patients admitted with ES according to current European Society of Cardiology guidelines. The aim of this study was the analysis of clinical profile, diagnostic and treatment pathway, and assessment of prognosis of patients with ES.

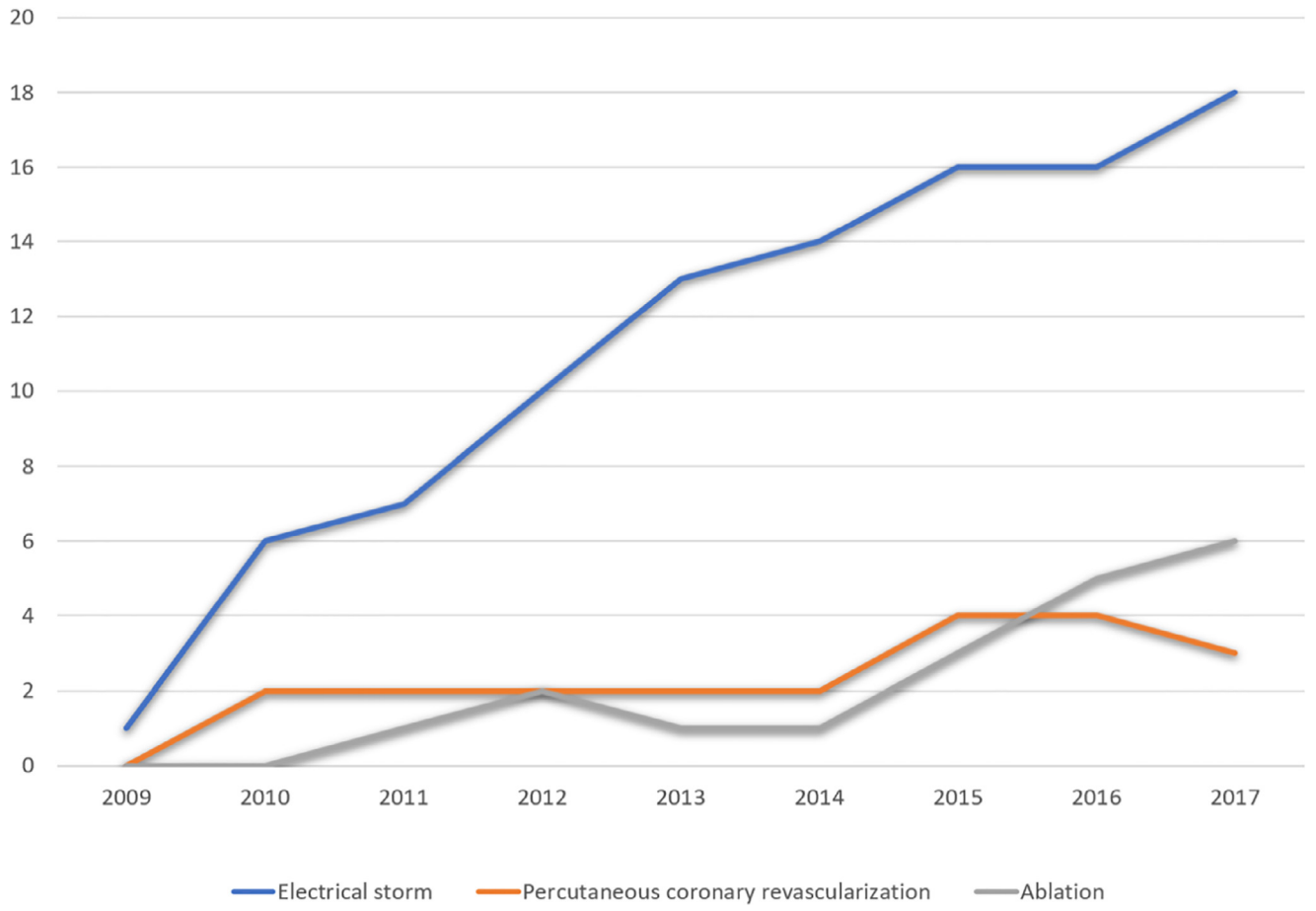

Figure 1. The trends of electrical storm and invasive treatment rate during the study period.

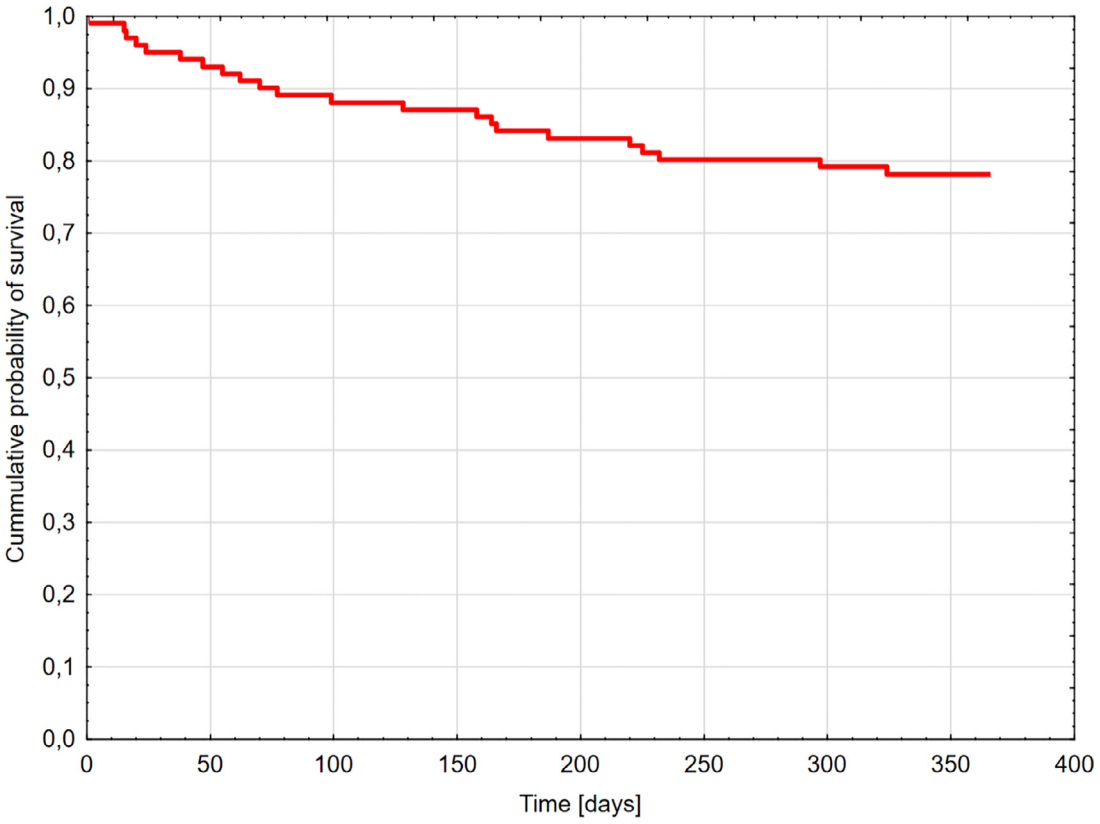

Figure 2. All-cause mortality in the population of patients with electrical storm.

Main implications of our paper are as follows: (1) the percentage of ES in the whole population with ICD/cardioverter-defibrillator was 3,9%, (2) the prevalence in study cohort are patients with ischemic etiology of HF, (3) over half of the patients were referred for coronary angiograms and 1/5 had at least one stent implanted due to significant narrowing of coronary arteries and 1/5 of the patients had ablation of VA, (4) the 12-month mortality was 21.8% and probability of ES recurrence was 15.8%, and (5) NYHA class III and IV at admission, raised levels of N-terminal fragment of prohormone B-type Natriuretic Peptide and creatinine, and decreased hemoglobin levels were independent predictors of 12-month mortality in the study population.

Table 4
In-hospital and follow-up data

Variable	n = 101
Time from device implantation to first electrical storm, days (IR)	621 (427−1207)
Time from electrical storm to death, median, days (IR)	220 (768)
Incidence of electrical storm	3.9%
In-hospital mortality	3%
In-hospital stroke or transient ischemic attack	0%
At least one another electric storm during 12-month	15.8%
30-days mortality	4.9%
12-month mortality	21.8%

IR = interquartil range.

It is proven that ES strongly increases incidence of death, mainly secondary to HF worsening.[9,13,14] Papers published previously do not give data of all treatment techniques used and usually concentrate on pharmacological treatment and ablation, rejecting revascularization effects or assuming, that it is not a target treatment of ES. Most documents describing subjects related to ES are either subanalyses of other trials or consist of small groups of patients.

Most patients with ES have cardiovascular implantable electronic device implanted mainly because of HF. About 2/3 of the cases of HF is caused by deterioration of function of left ventricle induced by ischemia. Having that on mind together with the fact, that ES is a life-threatening condition, invasive procedures: diagnostic (such as coronary angiography or electrophysiological study) and therapeutic (PCI, surgical revascularization or ablation) should be used in parallel, and not competitively. According to the authors

Table 5
Predictors of 12-month mortality in the study population (Cox proportional hazards model results)

NYHA III or IV on admission	8.53	1.12−16.83	0.03
Creatinine level (per 1 umol/L more)	1.02	1.004−1.04	0.02
NT pro-BNP (per pg/ml)	1.01	1.001−1.05	0.03
Hemoglobin (per 1 mmol/L less)	0.36	0.15−0.87	0.02

CI = confidence interval; HR = hazard ratio; NT pro-BNP = N-terminal fragment of prohormone B-type Natriuretic Peptide; NYHA = New York Heart Association; TIMI = thrombolysis in myocardial infarction.

of this article, all patients with ischemic etiology of HF or previously observed atherosclerotic changes in coronary arteries (even nonsignificant at the time of angiogram), should be referred for CA and undergo complete revascularization. Existence of possible reversible causes of ES in such patients does not exclude coexisting ischemia caused by progression of atherosclerosis of coronary arteries. Published clinical evidence suggest, that myocardial ischemia is a vital factor in case of sudden cardiac arrest or adequate intervention of ICD and indicate, that prophylactic revascularization of coronary arteries may lower VA burden in those patients[16] which may decrease mortality as suggested by the outcomes of patients from our registry. Intentional and complete revascularization of coronary arteries is indicated in patients, in whom myocardial ischemia may be present and is likely to cause recurrent VT/VF and in people, in whom underlying ischemic etiology of VA cannot be excluded.[17] It was proved, that revascularization of significantly narrowed coronary arteries decreases incidence of arrhythmia recurrence.[18]

VT ablation is indicated in case of insufficiency of pharmacotherapy, lack of reversible causes of ES and together with revascularization in patients with ES.[19] It is proven that VT ablation in patients with ES significantly decreases recurrence of VA and, in combination with optimal pharmacotherapy, may prolong life in those patients.[20] In many cases and due to electrical and hemodynamic instability, and/or patient's characteristics, abovementioned procedures are of high risk and require circulatory support. In recently published papers evaluating the clinical outcomes of patients receiving hemodynamic support (HS) during VT ablation it was shown, that patients requiring HS were sicker and had multiple co-morbidities, and had significantly higher 1-year mortality than patients in the non-HS group. In patients with left ventricle ejection fraction ≤20% and NYHA class III to IV, there was also no significant difference in clinical outcomes when compared with no HS group. Investigators underline, that further studies are necessary to evaluate patients who underwent VT ablation with HS.[21]

In case of severe VT storm, it may be management with a left ventricular assist device, but there are insufficient data regarding this method and only several case reports are available.[22]

There is an ongoing international study called ELECTRa, with 2 main aims of the study defined by its authors: to create an international registry on ES containing information about clinical features, pharmacological management and interventional treatment strategies, and to use the data derived from the registry to describe mortality and rehospitalization rates over a long follow-up in patients with ES.[23] Results of ELECTRa study are awaited, but the study design of this registry does not include results from other invasive methods then ablation. The survivors of electrical storm are the group with the highest risk of bad prognosis, hence treatment should be of broad spectrum and tailored for each. There is still insufficient data about how to treat such heterogeneous group. The percentage of patients treated invasively with PCI or ablation remains relatively low. A precise algorithm of treatment of ES, should help to unify diagnostic and therapeutic procedures and may result in better prognosis as well as would allow more adequate medical and scientific analysis of ES treatment. For those reasons authors feel, that data from real-life all-comers registries are of crucial weigh and on-going registries are necessary to allow comparison of effectiveness of treatment over years.

Disclosures

The authors have no conflicts of interest to declare.

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