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Contact feedback improves 1-year outcomes of remote magnetic navigation-guided ischemic ventricular tachycardia ablation

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ABSTRACT

Introduction: Remote magnetic navigation (RMN)-guided catheter ablation (CA) is a feasible treatment option for patients presenting with ischemic ventricular tachycardia (VT). Catheter-tissue contact feedback, enhances lesion formation and may consequently improve CA outcomes. Until recently, contact feedback was unavailable for RMN-guided CA. The novel e-Contact Module (ECM) was developed to continuously monitor and ensure catheter-tissue contact during RMN-guided CA.
Objective: The present study aims to evaluate the effect of ECM implementation on acute and long-term outcomes in RMN-guided ischemic VT ablation.
Method: This retrospective, two-center study included consecutive ischemic VT patients undergoing RMN-guided CA from 2010 to 2017. Baseline clinical data, procedural data, including radiation times, and acute success rates were compared between CA procedures performed with ECM (ECM+) and without ECM (ECM−). One-year VT-free survival was analyzed using Cox-proportional hazards models, adjusting for potential confounders: age, left ventricular function, VT inducibility at baseline and substrate based ablation strategy.
Results: The current study included 145 patients (ECM+ N = 25, ECM− N = 120). Significantly lower fluoroscopy times were observed in the ECM+ group (9.5 (IQR 5.3–13.5) versus 12.5 min (IQR 8.0–18.0), P = 0.025). Non-inducibility of the clinical VT at the end of procedure was observed in 92% ECM+ versus 72% ECM− patients (P = 0.19). ECM guidance was associated with significantly lower VT-recurrence rates during 1-year follow-up (16% ECM+ versus 40% ECM−; multivariable HR 0.29, 95%-CI 0.10–0.69, P = 0.021, reference group: ECM−).
Conclusion: Contact feedback by the ECM further decreases fluoroscopy exposure and improves VT-free survival in RMN-guided ischemic VT ablation.

1. Introduction

Catheter ablation (CA) is an important treatment option for patients with ischemic heart disease presenting with ventricular tachycardia (VT) [1,2]. CA is reported to decrease the likelihood of subsequent ICD shocks, prolongs the time to VT recurrence and decreases VT burden in patients diagnosed with ischemic VT [3–5]. Several CA techniques are currently available for ischemic VT ablation. Some studies reported superiority of remote magnetic navigation (RMN) over manual guided VT ablation, exhibiting lower procedure and fluoroscopy times, higher acute success rates, lower VT recurrence rates and less adverse events [6–8].

CA techniques are rapidly evolving and there is a continuous search for novel technologies to improve long-term success and reduce complication rates [2]. As the quality of contact between the catheter tip and the myocardial tissue is believed to be of vital importance for lesion formation [9], there has been a focus on the development of technologies providing contact feedback. Contact force (CF) sensing catheters appeared to be beneficial in manual guided atrial fibrillation ablation [10]. However, in an observational study of VT ablations, the use of CF sensing catheters was still inferior to RMN-guided CA with respect to procedural outcome, long-term outcomes and safety [7]. A possible explanation for the lack of benefit of CF sensing catheters in manual VT ablation is the loss of tissue contact during ventricular contraction which can be maintained with RMN. In RMN-guided CA, contact feedback

Abbreviations: ATP, anti-tachy pacing; BMI, body mass index; CA, catheter ablation; CABG, coronary bypass grafting; CF, contact force; ECM, e-Contact Module; EF, ejection fraction; EP, electrophysiology; EPS, electrophysiology study; ICD, implantable cardioverter defibrillator; IQR, interquartile range; LV, left ventricle; MAN, manual; PCI, percutaneous coronary intervention; PES, programmed electrical stimulation; PVC, premature ventricular complex; RF, radiofrequency; RMN, remote magnetic navigation; RV, right ventricle; VT, ventricular tachycardia.

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only recently became available with the development of the e-Contact Module (ECM). The present study aims to evaluate the effect of the ECM on RMN-guided ischemic VT ablation outcomes. Our primary hypothesis is that use of the ECM benefits lesion formation, resulting in lower VT recurrence.

2. Methods

2.1. Study design

This study is a retrospective, two-center study investigating ischemic VT ablation procedures performed with RMN. Index procedures performed with the ECM (ECM+) were compared with index procedures performed without ECM (ECM−). Primary endpoint was the freedom of VT recurrence during 12-months of follow-up (FU). We also analyzed the following secondary endpoints: procedural parameters (including radiation times), acute procedure success, complication rates, the redo procedure rates and all-cause mortality at 12-months of follow-up (FU). Additionally, the ICD therapy burden during the 12 months anticipating and the 12 months following the index procedure were evaluated, as well as the proportion of ECM guided applications applied in optimal or suboptimal contact. The local ethical committees approved data collection (MEC-2018-1114 and WO 15.142). The study protocol conforms to the ethical guidelines of the 1975 Declaration of Helsinki. Procedural informed consent was obtained from all the patients prior to the electrophysiological study (EPS).

2.2. Study population

All consecutive patients undergoing the first RMN-guided CA procedure for VT with an ischemic substrate in one of the two participating centers between January 2010 and December 2017 were included in this study. Patients with VTs caused by a non-ischemic cardiomyopathy were not eligible for inclusion. Participating centers were the Onze Lieve Vrouwe Gasthuis (OLVG, Amsterdam, the Netherlands) and the Erasmus Medical Center (Erasmus MC, Rotterdam, the Netherlands). Patients were eligible for VT ablation based on the most recent guidelines and recommendations at the time of procedure [1,2]. Because of the long inclusion time, additional sub-analysis of the more recently performed procedures only was performed (i.e. all procedures performed from April 2016 to December 2017).

2.3. Definitions

Index procedures were defined as the first RMN-guided VT ablation procedure performed in a patient in one of the participating centers within the mentioned time frame. All repeat VT ablation procedures following the index procedure were considered redo procedures. Acute procedure success was defined as non-inducibility of the clinical VT at the end of procedure. Recurrence of VT was regarded when a patient had a recurrence of a sustained VT, or VT treated with implantable cardioverter defibrillator (ICD) therapy (either anti-tachy pacing (ATP) or shock). Total procedure time was defined as the time from first puncture until the removal of catheters. Mapping time was defined as the time from start mapping (first point taken) until completion (last point taken), whereas ablation time was defined as time from first application until last application. Minor complications were pericardial effusion not requiring intervention and access site complications. Major complications were cardiac tamponade, hemorrhagic shock, stroke and procedure-related death. Chronic kidney disease was considered when a patient had an estimated Glomerular Filtration Rate (eGFR) using the CKD-EPI formula of 59 ml/min/1.73 m^2 or lower (i.e. chronic kidney disease (CKD) stage IIIa or higher).

2.4. Data collection

Baseline demographic and clinical characteristics were collected from the institutional electronic patient dossiers (HiX version 6.1 (ChipSoft BV, Amsterdam, NL) or Epic Hyperspace 2017 (Epic Systems Corporation, Verona, WI, USA)). Procedural data was derived both from the electronical medical files, as well as from the procedural log files recorded with the EP-workmate (St. Jude Medical Inc., St. Paul, MN, USA), the Niobe II or Niobe ES Magnetic Navigation System (Stereotaxis Inc., St. Louis, MO, US) and the Odyssey Cinema system (Stereotaxis Inc., St. Louis, MO, USA). All patient information was de-identified.

2.5. Procedural protocol

All CA procedures were performed in accordance with institutionally approved local medical treatment protocols of the OLVG and EMC. Ablation was performed targeting VTs induced by programmed electrical stimulation (PES) and/or modifying the electrical substrate. The left ventricle (LV) was accessed through a transaortic or transseptal approach based on the operator's preference. In all patients, electroanatomic maps were obtained while patients were in sinus rhythm with the Carto 3D mapping system as standard of care (CARTO 3 (Biosense Webster Inc., Diamond Bar, CA, USA)). Bipolar voltage criteria were used to identify scar (<0.5 mV), scar-border zone (0.51–1.49 mV) and healthy tissue (>1.5 mV). If not incessant, VT was induced by PES and activation or entrainment mapping was performed if VT was hemodynamically tolerable, to locate critical isthmuses and exit sites. The main target of scar-related VT ablation was the critical isthmus of hemodynamically stable sustained VT identified using conventional diagnostic criteria (i.e. middiastolic potentials). Another target was the exit of the VT circuit identified during activation mapping or pace mapping. In the case of hemodynamically unstable or noninducible sustained VT, substrate ablation was performed focused on areas within the scar demonstrating fractionation or late potentials during sinus rhythm. It was up to the operator's preference to perform substrate ablation in hemodynamically stable VT as well in addition to targeting critical isthmus and exit sites. Ablation was performed using the following radiofrequency settings: right ventricle (RV): 40–45 W, 20 ml/min, max 43 °C; LV: 50–55 W, 30 ml/min, max 43 °C. PES was performed at the end of the procedure to evaluate the effect of the applied therapy. RMN (Stereotaxis, Inc., St. Louis, MO, USA) was used in all cases.

2.6. Follow-up

Following the index procedure, all patients were checked at the outpatient clinic at regular intervals. Standard follow-up visits were: 6 months and 12 months after the procedure, including ICD check-up. Voluntary follow-up patients were: 3 months and 9 months after procedure. Some patients were seen even more frequently when they experienced VT recurrences. Some patients had their FU at referral hospitals. This data was also collected and included in the present study.

2.7. e-Contact Module

The ECM, a recently developed hardware and software module compatible with the Niobe ES RMN system, incorporates 16 types of data of three categories to determine whether the catheter is in contact with cardiac tissue or not. The following types of data are used to determine whether the catheter is in (optimal) contact with cardiac tissue: 1) electrical impedance measurements; 2) cardiac induced motion of the catheter tip; and 3) the torque being applied by the magnetic field. To confirm the different threshold levels of contact, qualitative assessments based on observations during pre-clinical studies were made while visually observing contact using intra-cardiac ultrasound. The contact assessment is visualized to the user as a starburst near the

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catheter tip and as a blue line on the contact tracing (Fig. 1). When there is minimal contact, the starburst is small, whereas in optimal contact the starburst is bolder. Without any contact, there is no starburst. The ECM was installed in the EMC in April 2016 and in the OLVG in July 2017.

2.8. Quality of contact

As contact is established by the ECM by a mathematical algorithm, calculated from 16 variables, as described above, this algorithm could be used to evaluate the quality of contact of all RF applications applied in patients included in the study. For every single RF application, its time being applied in either optimal, suboptimal or without contact with myocardial tissue was derived from the procedural log files recorded by the ECM and the Stereotaxis systems.

2.9. Statistical analysis

Normality was assessed by the Kolmogorov-Smirnov test, or when appropriate, Shapiro-Wilk test. Mean and standard deviation (SD) were calculated for normally distributed continuous variables. Median and interquartile range (IQR) were computed for continuous variables with non-normal distribution. Descriptive statistics for categorical data were expressed in absolute numbers and percentages. Continuous variables were compared between groups by the unpaired Student's *t*-tests. For variables with non-normal distributions, the Mann-Whitney *U* test was used. For comparing frequencies, the Chi-square test was used, or, when appropriate, Fisher's exact test. Univariable and Multivariable Cox proportional hazards models were used to examine the relationship between treatment group and long-term outcomes, adjusting for potential confounders. In all ECM+ patients, Cox proportional hazards models were also used to evaluate the relationship between the quality of contact as measured by the ECM and the long-term outcomes. A 2-sided P-value of <0.05 was considered significant. Data were analyzed using SPSS 24.0 (SPSS Inc., Chicago, IL, USA).

3. Results

This study included 187 RMN-guided VT ablation procedures, of which 145 were index procedures and 42 were redo procedures (Fig. 2). Of the 145 index procedures, 120 were performed without ECM (ECM−) and 25 with ECM (ECM+) guidance. In total, the OLVG included 91 patients (63%) and the Erasmus MC 54 patients (37%). In the OLVG, 5 patients (6%) were treated with ECM guidance, whereas in the Erasmus MC it was used in 20 patients (37%). In the OLVG, procedures were performed by 2 operators in total. The first operator from this center performed 95% of procedures, which was comparable between study groups. In the second center, 5 operators in total performed the procedures over time. First operator performed the majority of procedures (57%), the second operator performed 4%, the third 4%, the fourth 20% and the fifth 15% of procedures, which were also comparable between groups.

3.1. Demographic and baseline clinical data

Demographic and baseline clinical data are presented in Table 1. The mean age was 67.9 ± 9.6 years. The majority of patients had a poor LVEF <30% (N = 82 (57%)). At baseline, 83 (58%) patients were on amiodarone therapy. In total, 136 (94%) patients had an ICD. Baseline demographic and clinical data were not significantly different between groups, except for PCI being more frequently performed in the ECM+ group (ECM− 55% versus ECM+ 80%, P = 0.019).

Descriptive procedural parameters are also presented in Table 1. Epicardial ablation was performed in 3 patients (3%). The ECM was not applied to the epicardium in this study. In all ECM+ patients (N = 25, 100%) an ablation strategy including substrate ablation was applied versus in 83% of the ECM− patients (P = 0.024). In the 21 patients (14%) were no substrate ablation was performed, the ablation strategy focused on elimination of critical isthmuses and/or exit sites only.

3.2. Procedural outcome

Mean total procedure time was 200 ± SD 76 min and was comparable between groups (P = 0.12), as is shown in Table 2. The mean application duration was 1943 ± SD 1064 s. There was no significant difference between groups (ECM− 1823 ± SD 1117 s versus ECM+ 2119 ± SD 979 s, P = 0.29). Fluoroscopy time was significantly lower in ECM+ patients (9.5 (IQR 5.3–13.5) minutes versus 12.5 (IQR 8.0–18.0) minutes, P = 0.025). Moreover, the ablation time was

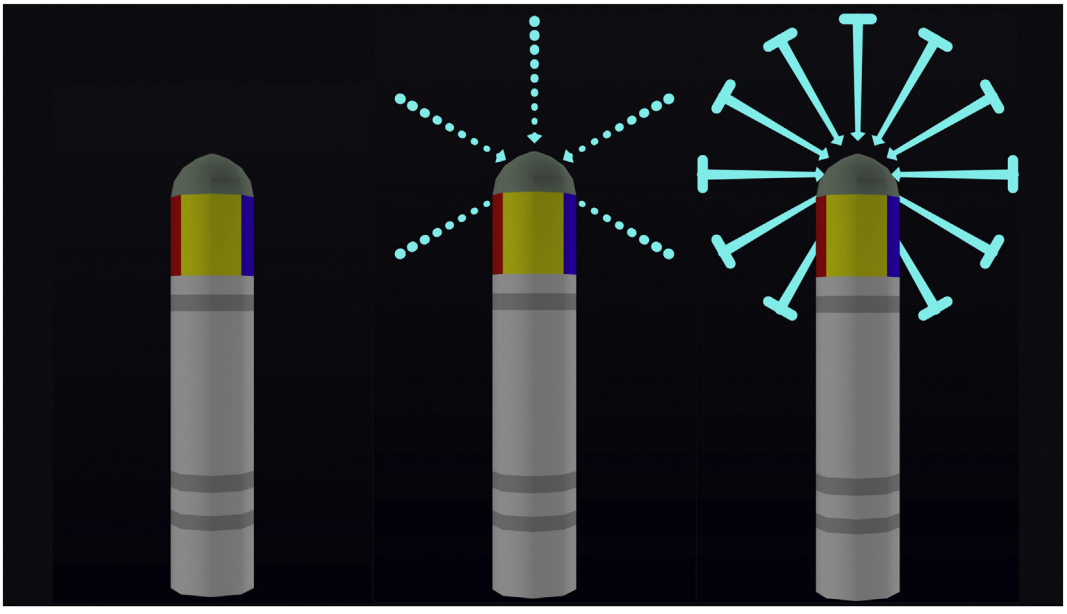

Fig. 1. The e-Contact Module. This figure shows the three types of output of the e-Contact Module. Left: When the catheter is not in contact with myocardial tissue, the ablation catheter is displayed without starburst. Middle: When the catheter is placed in contact with myocardial tissue, a starburst appears at the tip of the ablation catheter. Right: When the catheter is in optimal contact, a dense starburst is shown at the catheter tip.

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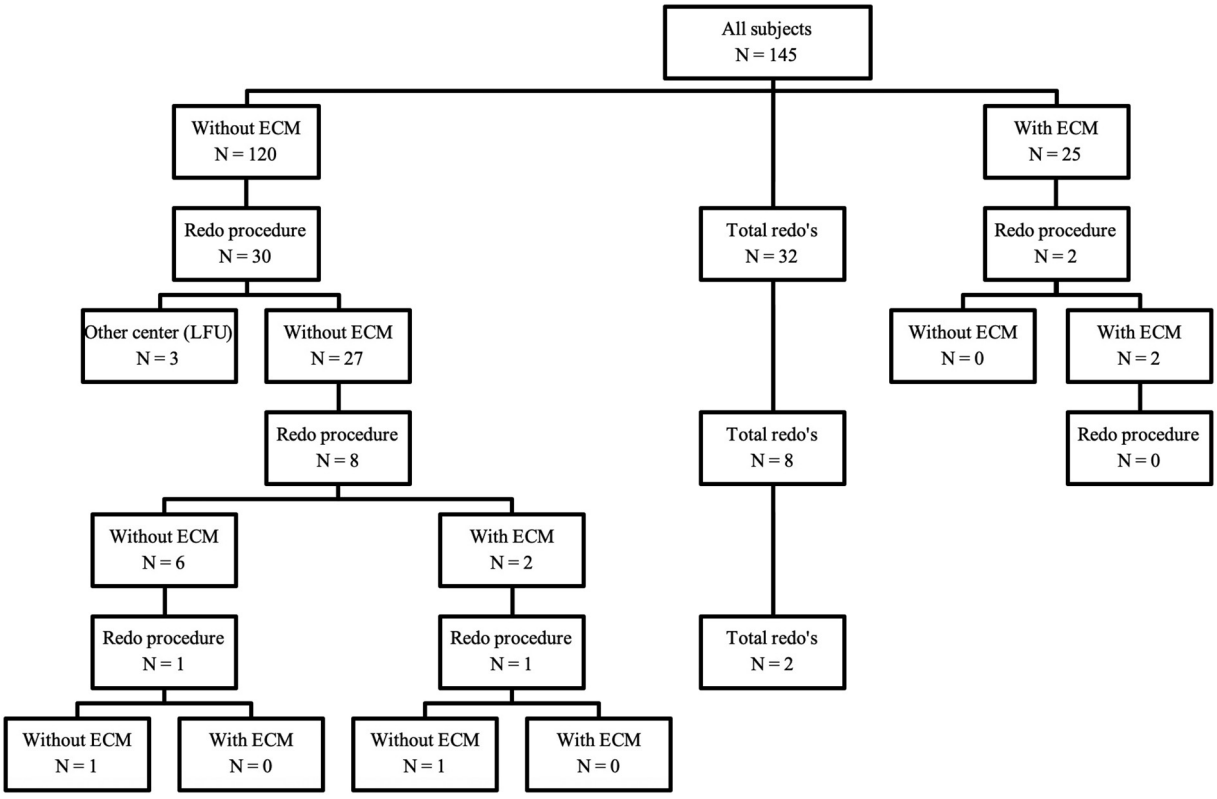

Fig. 2. Study population. The study population is presented in this figure. We included 145 index procedures in our study, of which 120 were performed without ECM and 25 with ECM guidance. In total 42 redo procedures were performed, which were all RMN guided CA procedures, some performed with and others without ECM guidance. ECM = e-Contact Module. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

significantly lower in ECM+ group (83 ± SD 49 versus 112 ± 60 min, P = 0.028), whereas the mapping times were comparable between groups. Non-inducibility of the clinical VT at the end of the procedure was observed in 115 patients (79%), whereas non-inducibility of all VT was observed in 84 patients (56%). The non-inducibility rates were comparable between groups (P = 0.19 and P = 0.27, respectively).

3.3. Long-term outcome

At 12-months FU, VT recurrence was observed in 48 (40%) ECM− patients, compared to 4 (16%) ECM+ patients (P = 0.023), as illustrated in Table 2. Moreover, ECM− patients were more frequently admitted to the hospital because of VT recurrence (39 (33%) ECM− versus 3 (12%) ECM+, P = 0.040). We observed a tendency towards more redo procedures performed in ECM− patients when compared to ECM+, although this was statistically not significant (30 (25%) versus 2 (8%) respectively, P = 0.06). Anti-arrhythmic drugs were stopped during FU in 22 patients (16%), which consisted predominantly of therapy with amiodarone and were comparable between groups. Twelve month FU data was incomplete in 11 patients (8%), which was comparable between groups (ECM− 8 patients (7%) versus ECM+ 3 patients (12%), P = 0.90).

CA procedures performed with ECM guidance (ECM+) were associated with improved VT-free survival during the 12 months of follow-up, when compared to ECM− (multivariable HR 0.29, 95%-CI 0.10–0.69, P = 0.021, with ECM− as the reference group) (Table 3a and Fig. 3). Age, gender, LVEF, VT inducibility at baseline EPS and an ablation strategy using substrate ablation, did not show a significant relation with the outcome. As a sensitivity analysis, center of procedure, medical history of PCI, non-inducibility of clinical VT at end of procedure and non-inducibility of all VT at end of procedure, were consecutively also added to the univariate and multivariate models, and did not show any significant associations with the primary outcome either (data not shown). There was no significant difference between groups in all-cause mortality (multivariable HR 1.47, 95%-CI 0.37–5.88, P = 0.59, with ECM− as the reference group) (Table 3b and Fig. 3), or in the redo procedure rates (multivariable HR 0.51, 95%-CI 0.11–2.33, P = 0.39, with ECM− as the reference group) (Table 3c). Age, gender, LVEF and an ablation strategy using substrate ablation, procedure center and medical history of PCI, did not show a significant relation with all-cause mortality and redo procedure rate. However, VT inducibility at baseline EPS was significantly related to a lower redo procedure rate (multivariable HR 0.43, 95%-CI 0.12–0.97, P = 0.044, with VT non-inducibility at baseline EPS as the reference group).

3.4. ICD therapy burden

In 120 patients who had an ICD implanted, the ICD therapy burden in the 12 months anticipating and 12 months following the index procedure was evaluated. In 16 patients, no pre-operative ICD data was available, as the ICD was implanted during the same hospital admission as the VT ablation procedure. Additionally, 9 patients did not have an ICD at all. Post-procedurally, a significant lower proportion of ECM+ patients experienced ICD shocks, as compared to ECM− patients (4% versus 24%, P = 0.048). A median reduction of 2.0 (IQR 0.0–10.0) ATP episodes and a median reduction of 1.0 (IQR 0.0–3.0) shock were observed after the VT ablation procedure (Table 4), which were comparable between groups.

3.5. Quality of contact

The quality of catheter-tissue contact during all ECM+ procedures was calculated and analyzed. The majority of the total application duration was applied in optimal contact (71% (IQR 42–83)). A small part of the total application duration was applied without contact (6% (IQR 1–17)), whereas 21% (IQR 7–29) of the total application duration was applied in suboptimal contact. There was no significant relation

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Table 1
Baseline demographic, clinical and procedural data.

	ECM− N = 120	ECM+ N = 25	Total N = 145	P-value
Age (years)[a]	67.5 ± 9.9	69.8 ± 7.7	67.9 ± 9.6	0.27
Female	24 (20%)	3 (12%)	27 (19%)	0.35
BMI (m/kg^2)[b]	26.9 (24.2–30.8)	26.0 (23.5–29.3)	26.4 (24.2–30.5)	0.44
Hypertension	46 (38%)	9 (36%)	55 (38%)	0.83
Diabetes	20 (17%)	6 (24%)	26 (18%)	0.39
Atrial fibrillation	40 (33%)	11 (44%)	51 (35%)	0.31
COPD	23 (19%)	5 (21%)	28 (19%)	0.85
Chronic kidney disease (Stage ≥ IIIa)	56 (48%)	15 (60%)	71 (50%)	0.27
eGFR (ml/min/1.73 m^2)	61 ± 19	60 ± 26	61 ± 20	0.85
Hemodialysis	2 (2%)	0 (0%)	2 (1%)	0.51
NYHA class I	30 (42%)	9 (45%)	39 (42%)	0.79
NYHA class II	18 (25%)	7 (35%)	25 (27%)	0.37
NYHA class III	24 (33%)	4 (20%)	28 (30%)	0.25
NYHA class IV	0 (0%)	0 (0%)	0 (0%)	1.00
Ischemic CMP	120 (100%)	25 (100%)	124 (100%)	1.00
Thrombolysis	12 (10%)	3 (12%)	15 (10%)	0.78
PCI	65 (55%)	20 (80%)	85 (59%)	**0.019**
CABG	37 (31%)	11 (44%)	48 (33%)	0.20
ICD	111 (93%)	25 (100%)	136 (94%)	0.16
VT storm	29 (24%)	4 (16%)	33 (23%)	0.38
LVEF				
Normal (≥55%)	5 (4%)	0 (0%)	5 (3%)	0.30
Mildly reduced (45–54%)	22 (18%)	3 (12%)	25 (17%)	0.45
Reduced (30–44%)	27 (23%)	6 (24%)	33 (23%)	0.87
Poor (<30%)	66 (55%)	16 (64%)	82 (57%)	0.41
(D)OAC	79 (66%)	18 (72%)	97 (67%)	0.55
Beta-blocker	98 (82%)	20 (80%)	118 (81%)	0.85
Ca-antagonist	5 (4%)	1 (4%)	6 (4%)	0.97
Amiodarone	66 (56%)	17 (68%)	83 (58%)	0.27
Sotalol	10 (8%)	3 (12%)	13 (9%)	0.56
Class 1a	4 (3%)	1 (4%)	5 (4%)	0.89
Class 1b	2 (2%)	2 (8%)	4 (3%)	0.08
Class 1c	0 (0%)	0 (0%)	0 (0%)	1.00
Procedural parameters				
Approach				
Right sided - transvenous	3 (3%)	0 (0%)	3 (2%)	0.42
Left sided - transseptal	8 (7%)	3 (12%)	11 (8%)	0.36
Left sided - transaortic	105 (88%)	22 (88%)	127 (86%)	0.95
Both right and left (transaortic)	4 (3%)	0 (0%)	4 (3%)	0.36
VT inducibility at baseline EPS	106 (88%)	18 (75%)	124 (86%)	0.18
Mapping during VT	76 (63%)	15 (60%)	91 (63%)	0.75
Number of VT morphologies[a]	2.0 (1.0–3.0)	1.0 (1.0–3.0)	2.0 (1.0–3.0)	0.10
VT cycle length (msec)[a]	391 ± 101	398 ± 70	392 ± 97	0.81
Location of ablation				
RV	7 (6%)	0 (0%)	7 (5%)	0.22
LV	117 (98%)	25 (100%)	142 (98%)	0.42
Epicardial	3 (3%)	0 (0%)	3 (2%)	0.42
Substrate modification	99 (83%)	25 (100%)	124 (86%)	**0.024**

BMI = body mass index, CABG = coronary artery bypass grafting, CKD-EPI = chronic kidney disease epidemiology collaboration, CMP = cardiomyopathy, COPD = chronic obstructive pulmonary disease, (D)OAC = (direct) oral anticoagulant, ECM = e-Contact Module, eGFR = estimated Glomerular Filtration Rate (using the CKD-EPI formula), ICD = implantable cardioverter defibrillator, LV = left ventricle, LVEF = left ventricular ejection fraction, PCI = percutaneous intervention, RV = right ventricle, VT = ventricular tachycardia.
[a] Mean ± SD.
[b] Median (IQR).

between the type of contact and the 12-month VT recurrence rates (applications applied without any contact: univariate HR 1.02, 95% CI 0.98–1.06, P = 0.407; applications applied in suboptimal contact: univariate HR 0.94, 95% CI 0.86–1.04, P = 0.227; applications applied in optimal contact: univariate HR 1.00, 95% CI 0.96–1.04, P = 0.958). Figure 4 illustrates a case example showing an application applied in optimal and suboptimal contact respectively (Fig. 4). There were no significant

Table 2
Acute and long-term outcomes.

	ECM− N = 120	ECM+ N = 25	Total N = 145	P-value
Acute outcomes				
Total procedure time (min)[a]	206 ± 79	175 ± 56	200 ± 76	0.12
Total application duration (sec)	1823 ± 1117	2119 ± 979	1943 ± 1064	0.29
Total fluoroscopy time (min)[b]	12.5 (8.0–18.0)	9.5 (5.3–13.5)	11.0 (7.2–17.3)	**0.025**
Total mapping time (min)	47 ± 26	55 ± 24	49 ± 26	0.16
Total ablation time (min)	112 ± 60	83 ± 49	105 ± 59	**0.028**
Non-inducibility clinical VT	92 (77%)	23 (92%)	115 (79%)	0.19
Non-inducibility all VT	66 (55%)	19 (76%)	85 (59%)	0.15
12 month outcomes				
VT recurrence	48 (40%)	4 (16%)	52 (36%)	**0.023**
Hospital admission for VT recurrence	39 (33%)	3 (12%)	42 (29%)	**0.040**
Redo procedure	30 (25%)	2 (8%)	32 (22%)	0.06
Stop of ADD	17 (15%)	5 (21%)	22 (16%)	0.44
All-cause mortality	9 (8%)	3 (12%)	12 (8%)	0.46

ADD = anti-arrhythmic drugs, ECM = e-Contact Module, VT = ventricular tachycardia.
[a] Mean ± SD.
[b] Median (IQR).

associations between LV approach (transaortic or transseptal) and the measured quality of contact.

3.6. Safety data

Major and minor complication rates were not significantly different between groups (major: 3% versus 0%, P = 0.42; minor: 8% versus 12%, P = 0.56). Major complications were CVA (1 patient, who had post-procedural hemianopia and dysartria which improved significantly 5 days after the procedure), a complete AV block (1 patient, who already

Table 3
Cox proportional hazard models for VT recurrence, all-cause mortality and Redo procedure rates.

	Univariable model			Multivariable model		
	Hazard ratio[a]	95% CI	P-value	Hazard ratio[a]	95% CI	P-value
VT-recurrence						
ECM guidance	0.34	0.12–0.95	**0.040**	0.29	0.10–0.69	**0.021**
Age	1.01	0.99–1.04	0.35	1.01	0.98–1.04	0.48
LVEF <45%	1.66	0.75–3.70	0.21	1.85	0.83–4.17	0.14
VT inducibility at baseline EPS	0.62	0.30–1.27	0.19	0.53	0.25–1.14	0.10
Substrate modification	0.80	0.39–1.64	0.55	1.02	0.49–2.17	0.95
All-cause mortality						
ECM guidance	1.56	0.42–5.88	0.50	1.47	0.37–5.88	0.59
Age	1.03	0.97–1.10	0.40	1.03	0.96–1.09	0.42
LVEF <45%	0.37	0.05–2.86	0.34	2.50	0.32–20.00	0.38
VT inducibility at baseline EPS	0.81	0.18–3.70	0.78	0.97	0.20–4.55	0.97
Substrate modification	0.94	0.20–4.35	0.94	0.92	0.19–4.55	0.92
Redo procedure						
ECM guidance	0.48	0.11–2.04	0.32	0.51	0.11–2.33	0.39
Age	0.99	0.95–1.03	0.60	0.98	0.94–1.02	0.30
LVEF <45%	1.09	0.37–3.23	0.88	1.12	0.38–3.33	0.83
VT inducibility at baseline EPS	0.47	0.17–1.27	0.14	0.34	0.12–0.97	**0.044**
Substrate modification	2.27	0.88–5.88	0.09	0.41	0.15–1.12	0.08

ECM = e-Contact Module, EPS = electrophysiology study, LVEF = left ventricular ejection fraction, VT = ventricular tachycardia.
[a] Hazard ratios were calculated using the following reference groups: no ECM guidance (ECM−), normal LVEF, VT non-inducibility at baseline EPS, no substrate modification performed.

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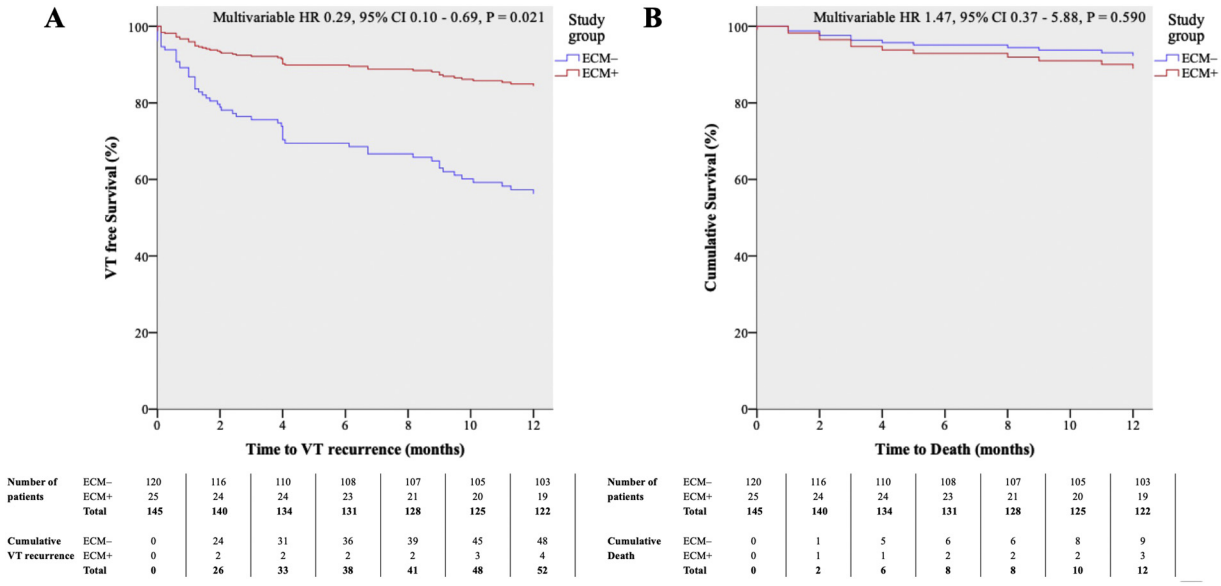

Fig. 3. Cumulative VT free survival (A) and overall survival (B) of patients treated with e-Contact Feedback (ECM+) versus patients treated without e-Contact Feedback (ECM−). This figure shows the survival curves of VT-recurrence and all-cause mortality, which were evaluated by Cox proportional hazards models. Panel A displays the VT-free survival during 12 months of follow-up. A significant higher VT-free survival was observed in patients treated with ECM guidance (ECM+) (multivariable HR 0.29, 95% CI 0.10–0.69, P = 0.021, for VT recurrence with ECM− as the reference group). Panel B shows the all-cause mortality during 12 months of follow-up, as evaluated by Cox proportional hazards models. The all-cause mortality was not significantly different between patients treated with the ECM connected (ECM+) and those treated without ECM (ECM−) (multivariable HR 1.47, 95% CI 0.37–5.88, P = 0.586, for all-cause mortality with ECM− as the reference group). ECM = e-Contact Module, HR = hazard ratio, LVEF = left ventricular ejection fraction, VT = ventricular tachycardia.

had an DDD-ICD implanted) and RV tab during attempting pericardial access. The RV tab was initially dry and therefore the procedure was continued, however a few hours after completion of the procedure the patient developed cardiac tamponade for which pericardiocentesis was performed (1 patient, who recovered without sequelae). The majority of minor adverse events were access site complications.

Table 4
ICD therapy burden.

	ECM− N = 95	ECM+ N = 25	Total N = 120	P-value
12 months pre-procedure				
Documented VT	95 (100%)	25 (100%)	120 (100%)	1.00
If yes, number of VT episodes[a]	5.0 (2.0–15.0)	6.0 (4.0–18.0)	5.0 (3.0–14.8)	0.52
ATP performed	69 (73%)	19 (76%)	88 (73%)	0.29
If yes, number of ATP episodes	5.0 (3.0–14.0)	6.0 (5.0–39.0)	5.0 (3.0–17.0)	0.10
Shock performed	66 (70%)	13 (52%)	79 (66%)	0.10
If yes, number of Shocks	2.0 (1.0–4.0)	2.0 (1.0–8.0)	2.0 (1.0–5.0)	0.19
12 months post-procedure				
Documented VT	48 (50%)	4 (16%)	52 (43%)	**0.023**
If yes, number of VT episodes	3.0 (1.0–10.5)	21.0 (5.0–99.3)	3.0 (1.0–12.5)	0.05
ATP performed	31 (33%)	4 (16%)	35 (29%)	0.22
If yes, number of ATP episodes	3.0 (1.5–8.0)	21.0 (4.3–99.3)	3.0 (2.0–10.0)	0.39
Shock performed	23 (24%)	1 (4%)	24 (20%)	**0.048**
If yes, number of Shocks	2.0 (1.0–5.0)	1.0 (1.0–1.0)	2.0 (1.0–4.5)	0.09
Reduction				
VT episode reduction	3.0 (1.0–10.3)	5.0 (1.5–18.0)	4.0 (1.0–11.0)	0.23
ATP episode reduction	2.0 (0.0–7.5)	5.0 (0.8–39.0)	2.0 (0.0–10.0)	0.09
Shock reduction	1.0 (0.0–3.0)	1.0 (0.0–3.5)	1.0 (0.0–3.0)	0.80

ECM = e-Contact Module, VT = ventricular tachycardia, ICD = implantable cardioverter defibrillator, ATP = anti-tachy pacing, CA = catheter ablation.
[a] Median (IQR).

3.7. Sub-analysis of more recently performed procedures only

The sub-analysis of more recently performed procedures only (i.e. all procedures from April 2016 onwards), showed that in this period, 34 patients were treated without ECM (ECM−) and 25 patients with ECM guidance (ECM+) (Supplementary Material).

In this selected patient cohort, several demographic, clinical and procedural parameters differed significantly between the two groups at baseline, including: gender, thrombolysis performed in the past, PCI performed in the past, VT inducibility at baseline EPS, number of induced VT morphologies at baseline EPS and LV approach (retrograde aortic versus transseptal) (Table 1 – Supplementary Material).

With respect to the long-term outcomes, significantly lower 12-month VT recurrence rates in the ECM+ group were observed. VT recurrence was found in 38% of ECM− patients versus 16% of ECM+ patients (P = 0.042) (Table 2 – Supplementary Material). Cox proportional hazards models of the subgroup showed that ECM guidance (ECM+) was associated with improved VT-free survival during the 12 months of follow-up, when compared to ECM− (Univariable HR 0.29, 95%–CI 0.10–0.88, P = 0.028 and Multivariable HR 0.21, 95%–CI 0.06–0.71, P = 0.012, with ECM− as the reference group). Age, gender, LVEF, VT inducibility at baseline EPS and an ablation strategy using substrate ablation, consistently did not show a significant association with the outcome (Table 3 – Supplementary Material).

4. Discussion

This is the first study to assess the clinical outcome of contact feedback in RMN-guided CA. Our results suggest that contact feedback by the ECM improves VT free survival in RMN-guided ischemic VT ablation.

4.1. The importance of catheter-tissue contact

Effective lesion formation is a major determinant of outcome in VT ablation. In addition to traditional indices of power and RF duration, lesion continuity, catheter stability and contact have emerged as key elements influencing effective lesion formation [11]. Different contact

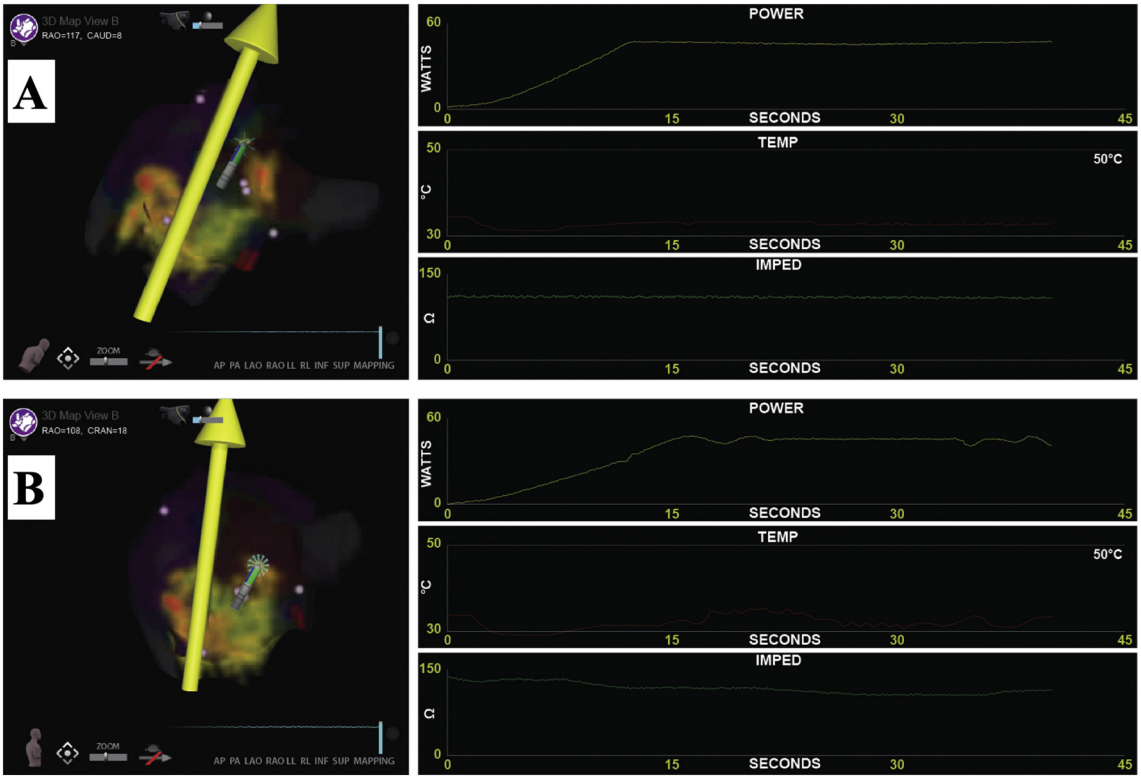

Fig. 4. Case example. This figure is a case example of one of the patients from our cohort treated with ECM guidance. At the left end, CARTO electroanatomic maps of the left ventricle are displayed. The electroanatomic maps are displayed more transparent, whereas previous ablation points are displayed in less-transparent yellow and orange (i.e. the "Ablation History" feature of the Stereotaxis system). On the right, ablation parameters of the currently performed application are displayed, including temperature, power and impedance (recorded by the Claris system). Panel A displays an application applied in suboptimal contact. The suboptimal catheter-tissue contact is shown to the user by the ECM as a small starburst at the catheter tip. One can appreciate that during this specific application the impedance was stable. On the contrary, Panel B shows an application applied in optimal catheter-tissue contact (visualized by a dense starburst at the catheter tip), where we observed a gradual impedance drop during ablation, which is related to improved lesion quality. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

matters are of importance, including contact homogeneity across a line of ablation, spatiotemporal dynamics of contact governed by cardiac and respiratory motion and contact directionality [11]. Moreover, contact is of critical importance in adequate three-dimensional electroanatomic mapping, another determinant of substrate ablation outcome [12]. This is illustrated by when a normal region is mislabeled as low-voltage scar due to poor tissue contact. Improved contact permits to define the areas of reduced potentials [12] and increases the sensitivity of late potential detection [13]. The present study observed that implementation of a novel contact assessing technology during RMN-guided ischemic VT ablation, resulted in higher VT-free survival. Consistently, less ICD shocks and less hospital admissions for VT recurrence were observed. Hypothetically, two factors are the key elements explaining how the ECM improved ablation outcome. First of all, real-time contact feedback potentially improves the efficacy of VT ablation by virtue of more accurate maps [12]; points were predominantly taken when the ECM showed that there was optimal catheter-tissue contact. Secondly, by optimizing lesion formation [11]; the RF application was only started when the ECM showed there was optimal contact and catheter position was continuously optimized by the operator during ablation. It would be interesting to further investigate the ECM's exact determination of size, definition and resolution of low-voltage areas in future studies involving scar related VT.

4.2. Remote magnetic navigation versus manual guided VT ablation

Where manual ablation catheters are still confined to uni- or bidirectional movement using pull wires [8], magnetic navigation ensures enhanced maneuverability of the ablation catheter that makes reach of difficult anatomical structures possible [14,15]. Magnetic guided ablation by itself aids to achieve more adequate lesion formation by enhanced catheter stability and consequently improved contact with the myocardial wall [16,17]. This is of critical importance in cardiac regions with greater wall motion excursion such as the ventricle. RMN facilitates titration of CF between the catheter and the myocardial tissue. Most studies comparing manual with RMN-guided VT ablation, reported superiority of RMN, with respect to procedure and fluoroscopy times, acute success rates and adverse events [7,8]. Moreover, in VT ablation of patients with non-structural heart disease, RMN reported significantly lower VT recurrence rates during long-term FU [6]. The present study reported lower procedure, fluoroscopy and mapping times, when compared to prior studies evaluating RMN guided ablation of scar related VT [18]. Moreover, we observed even further reduction of VT recurrence, ablation time and fluoroscopy exposure after implementation of the ECM. In our opinion this illustrates the technological advances made in RMN guided ablation over time and highlights that the ECM was rapidly embedded in daily practice by the operating electrophysiologists.

4.3. The e-Contact Module

CF in manual guided CA is determined electromechanically based on the amount of mechanical deformation or diffraction of light experienced by the catheter tip [19]. In contrast to CF sensing catheters in manual guided CA, the ECM does not inform on the quantity of force applied. In RMN's ECM, contact in fact is calculated by a combination of factors including the vector of the ablation catheter, wall motion and impedance. The ECM in RMN-guided ablation takes into account the angle between the tip of the catheter and myocardial surface that affects the pattern of the systodiastolic contact. In larger scars contact

measurements may be less reliable, there wall motion may be distorted due to akinesia or dyskinesia and impedance is altered due to changes in conduction properties. Yet, the ECM incorporates 16 variables to gauge contact that aids to high accuracy. The results of the present study, are in our opinion a confirmation of the accuracy of this novel feature, assisting to the composition of accurate maps and advancing effective lesion formation.

4.4. The quality of contact

This study also evaluated the measured quality of contact of every single RF application. According to the ECM, we observed that 92% of the total RF application time was applied in contact with myocardial tissue, of which >70% was applied in optimal contact. Six percent of the total RF application time was applied without any contact with the myocardium. Interestingly, even though not all applications were applied in optimal contact, we observed improved outcomes. Real-time contact feedback of the ECM, allows operators to constantly optimize catheter position while ablating reducing cumulative application time in suboptimal catheter position. Whether this explains the improved 12-month outcome in this study, should be verified in future studies where the operator is blinded versus unblinded to the ECM. Moreover, it would be interesting to investigate the effect of other parameters, such as LV approach, on the measured quality of contact.

4.5. Limitations

The present study's retrospective nature and the lack of blinded adjudication might have introduced bias, although this was mitigated by the use of objective measures. The present study included all procedures performed since the implementation of ECM. As the operators had to learn how to incorporate the ECM's feedback in their procedural approach, this learning curve might have negatively affected our results. Nevertheless, we observed a significantly better long-term outcome in procedures performed with ECM. Nowadays substrate ablation is being performed as per standard of care in all patients, whereas in the earlier days sometimes the procedure focused on elimination of critical isthmus and exit sites only. Moreover, insights on substrate ablation methodology changed over time. Possibly, it led to an improved abolition of channels [20,21] and this could have biased our results. However, substrate ablation as potential confounder was added to the Cox proportional hazard models and did not show a significant relation with the outcomes.

5. Conclusion

Contact feedback by the ECM appears to improve 1-year outcome in RMN-guided ischemic VT ablation, resulting in a higher 1-year VT free survival. Moreover, implementation of the ECM significantly reduces fluoroscopy exposure. These observations are most likely the result of improved accuracy of mapping and advanced ablation lesion formation due to the contact feedback provided by the ECM.

CRediT authorship contribution statement

Anna Maria Elisabeth Noten: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data curation, Visualization, Writing - original draft. **Astrid Armanda Hendriks:** Conceptualization, Methodology, Validation, Formal analysis, Investigation, Writing - original draft. **Sing-Chien Yap:** Methodology, Validation, Writing - review & editing. **Daniel Mol:** Methodology, Validation, Investigation, Writing - review & editing. **Rohit Bhagwandien:** Methodology, Validation, Writing - review & editing. **Sip Wijchers:** Methodology, Validation, Writing - review & editing. **Isabella Kardys:** Validation, Formal analysis, Writing - original draft. **Muchtiar Khan:** Conceptualization, Methodology, Validation, Writing - review & editing. **Tamas Szili-Torok:** Conceptualization, Methodology, Validation, Writing - original draft, Supervision.

Declaration of competing interest

None.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijcard.2020.05.028.

References

[1] S.G. Priori, C. Blomstrom-Lundqvist, A. Mazzanti, N. Blom, M. Borggrefe, J. Camm, et al., 2015 ESC Guidelines for the management of patients with ventricular arrhythmias and the prevention of sudden cardiac death: the Task Force for the Management of Patients with Ventricular Arrhythmias and the Prevention of Sudden Cardiac Death of the European Society of Cardiology (ESC). Endorsed by: Association for European Paediatric and Congenital Cardiology (AEPC), Eur. Heart J. 36 (41) (2015) 2793–2867.
[2] E.M. Aliot, W.G. Stevenson, J.M. Almendral-Garrote, F. Bogun, C.H. Calkins, E. Delacretaz, et al., EHRA/HRS Expert Consensus on Catheter Ablation of Ventricular Arrhythmias: developed in a partnership with the European Heart Rhythm Association (EHRA), a Registered Branch of the European Society of Cardiology (ESC), and the Heart Rhythm Society (HRS); in collaboration with the American College of Cardiology (ACC) and the American Heart Association (AHA), Europace 11 (6) (2009) 771–817.
[3] K.H. Kuck, A. Schaumann, L. Eckardt, S. Willems, R. Ventura, E. Delacretaz, et al., Catheter ablation of stable ventricular tachycardia before defibrillator implantation in patients with coronary heart disease (VTACH): a multicentre randomised controlled trial, Lancet 375 (9708) (2010) 31–40.
[4] E. Delacretaz, R. Brenner, A. Schaumann, L. Eckardt, S. Willems, H.F. Pitschner, et al., Catheter ablation of stable ventricular tachycardia before defibrillator implantation in patients with coronary heart disease (VTACH): an on-treatment analysis, J. Cardiovasc. Electrophysiol. 24 (5) (2013) 525–529.
[5] V.Y. Reddy, M.R. Reynolds, P. Neuzil, A.W. Richardson, M. Taborsky, K. Jongnarangsin, et al., Prophylactic catheter ablation for the prevention of defibrillator therapy, N. Engl. J. Med. 357 (26) (2007) 2657–2665.
[6] T. Szili-Torok, B. Schwagten, F. Akca, T. Bauernfeind, L.D. Abkenari, D. Haitsma, et al., Catheter ablation of ventricular tachycardias using remote magnetic navigation: a consecutive case-control study, J. Cardiovasc. Electrophysiol. 23 (9) (2012) 948–954.
[7] A.A. Hendriks, F. Akca, L. Dabiri Abkenari, M. Khan, R. Bhagwandien, S.C. Yap, et al., Safety and clinical outcome of catheter ablation of ventricular arrhythmias using contact force sensing: consecutive case series, J. Cardiovasc. Electrophysiol. 26 (2015) 1224–1229.
[8] P. Aagaard, A. Natale, D. Briceno, H. Nakagawa, S. Mohanty, C. Gianni, et al., Remote magnetic navigation: a focus on catheter ablation of ventricular arrhythmias, J. Cardiovasc. Electrophysiol. 27 (Suppl. 1) (2016) S38–S44.
[9] D.E. Haines, Determinants of lesion size during radiofrequency catheter ablation: the role of electrode-tissue contact pressure and duration of energy delivery, J. Cardiovasc. Electrophysiol. 2 (6) (2008) 509–515.
[10] V.Y. Reddy, S.R. Dukkipati, P. Neuzil, A. Natale, J.P. Albenque, J. Kautzner, et al., Randomized, controlled trial of the safety and effectiveness of a contact force-sensing irrigated catheter for ablation of paroxysmal atrial fibrillation: results of the TactiCath Contact Force Ablation Catheter Study for Atrial Fibrillation (TOCCASTAR) study, Circulation 132 (10) (2015) 907–915.
[11] N. Ariyarathna, S. Kumar, S.P. Thomas, W.G. Stevenson, G.F. Michaud, Role of contact force sensing in catheter ablation of cardiac arrhythmias: evolution or history repeating itself? JACC Clin. Electrophysiol. 4 (6) (2018) 707–723.
[12] J.J. Sanchez Munoz, P. Penafiel Verdu, J. Martinez Sanchez, M. Salar Alcaraz, M. Valdes Chavarri, Alberola A. Garcia, Usefulness of the contact force sensing catheter to assess the areas of myocardial scar in patients with ventricular tachycardia, Rev. Esp. Cardiol. (Engl. Ed.) 68 (2) (2015) 159–160.
[13] H. Mizuno, P. Vergara, G. Maccabelli, N. Trevisi, S.C. Eng, C. Brombin, et al., Contact force monitoring for cardiac mapping in patients with ventricular tachycardia, J. Cardiovasc. Electrophysiol. 24 (5) (2013) 519–524.
[14] L. Parreira, D. Cavaco, K. Reis-Santos, P. Carmo, D. Cabrita, M. Scanavacca, et al., Remote magnetic navigation for mapping and ablation of right and left ventricular outflow tract arrhythmias, Rev. Port. Cardiol. 32 (6) (2013) 489–495.
[15] M.N. Faddis, W. Blume, J. Finney, A. Hall, J. Rauch, J. Sell, et al., Novel, magnetically guided catheter for endocardial mapping and radiofrequency catheter ablation, Circulation 106 (23) (2002) 2980–2985.
[16] D.R. Davis, A.S. Tang, M.H. Gollob, R. Lemery, M.S. Green, D.H. Birnie, Remote magnetic navigation-assisted catheter ablation enhances catheter stability and ablation success with lower catheter temperatures, Pacing Clin. Electrophysiol. 31 (7) (2008) 893–898.
[17] A. Bhaskaran, M.A. Barry, S.I. Al Raisi, W. Chik, D.T. Nguyen, J. Pouliopoulos, et al., Magnetic guidance versus manual control: comparison of radiofrequency lesion dimensions and evaluation of the effect of heart wall motion in a myocardial phantom, J. Interv. Card. Electrophysiol. 44 (1) (2015) 1–8.

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[18] L.D. Biase, R. Tung, J.D. Burkhardt, J. Romero, C. Trivedi, S. Mohanty, et al., Abstract 14384: scar homogeneization ablation in patients with ischemic cardiomyopathy: comparison between remote magnetic navigation and manual ablation, Circulation 132 (suppl_3) (2015), A14384-A. .

[19] F. Sacher, M. Wright, N. Derval, A. Denis, K. Ramoul, L. Roten, et al., Endocardial versus epicardial ventricular radiofrequency ablation: utility of in vivo contact force assessment, Circ. Arrhythm. Electrophysiol. 6 (1) (2013) 144–150.

[20] P. Vergara, C. Roque, T. Oloriz, P. Mazzone, Bella P. Della, Substrate mapping strategies for successful ablation of ventricular tachycardia: a review, Arch. Cardiol. Mex. 83 (2) (2013) 104–111.

[21] F. Sacher, H.S. Lim, N. Derval, A. Denis, B. Berte, S. Yamashita, et al., Substrate mapping and ablation for ventricular tachycardia: the LAVA approach, J. Cardiovasc. Electrophysiol. 26 (4) (2015) 464–471.

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