Received: 31 July 2018 | Revised: 19 September 2018 | Accepted: 9 October 2018

DOI: 10.1002/joa3.12137

ORIGINAL ARTICLE

WILEY Journal of Arrhythmia Open Access

Updated results on catheter ablation of ventricular arrhythmias arising from the papillary muscles of the left ventricle

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Abstract

Background: Catheter ablation of ventricular arrhythmias (VAs) arising from the left ventricle`s (LV) papillary muscles (PM) is challenging. In this study we present results of catheter ablation using multiple energy sources and image-based approaches.

Methods: Fifty-three patients (49 ± 17 years old; 34% females; median LV ejection fraction 53 ± 11%) underwent catheter cryoablation or radiofrequency (RF) ablation with non-contact force sensing (Non-CFS) catheters and cardiac computed tomography integration (CTII) into the electroanatomical mapping system or contact force sensing RF (CFS RF) ablation catheters and intracardiac echo-facilitated 3D electroanatomical mapping. Ventricular arrhythmias foci were mapped at either the anterolateral (ALPM) or posteromedial papillary muscles (PMPM). Ablation was performed using an 8-mm cryoablation catheter (CRYO); a Non-CFS 4-mm open-irrigated RF catheter; or a CFS RF 3.5-mm open-irrigated tip catheter, via transmitral or transaortic approach.

Results: Acute success rate was 83% for Non-CFS RF/CTII; 100% for CRYO/CTII (n = 16) and CFS RF/ICE3D (n = 14) (P = 0.03). Catheter stability was achieved in all patients treated with Cryo/CTII. VA recurrence at 12 months follow-up was 48% (n = 11) for Non-CFS RF/CTII; 19% (n = 3) for CRYO/CTII; and 7% (n = 1) for CFS RF/ICE3D (P = 0.02).

Conclusions: Non-CFS/CTII was associated with an increased risk of recurrence of the clinical arrhythmia. Ablation with either CFS RF/ICE3D or CRYO/CTII showed high acute success rates and low recurrence rates during follow-up. Cryoablation provided stable contact and was less arrhythmogenic.

KEYWORDS

catheter ablation, intracardiac echocardiography, intracardiac ultrasound, ventricular arrhythmia, ventricular tachycardia

1 | INTRODUCTION

The papillary muscles (PMs) of the left ventricle (LV) are potential sites of origin of ventricular arrhythmias (VAs).[1] Catheter ablation has been described as an effective treatment, although radiofrequency (RF) delivery at these regions has been associated with poor catheter stability and high recurrence.[2] Cryo-energy can provide stable contact and lower recurrence rates.[3,4] Nevertheless, information regarding PM VAs ablation approaches is still lacking.

This study is meant as an up-date of our previous research, in which the use of contact force sensing catheters and advance electroanatomical mapping systems were lacking, as a major limitation. We sought to describe procedural outcomes and recurrence rates after catheter ablation of PM VAs using different energy sources: 1-Non-CFS RF, 2-Cryoablation (CRYO), and 3-CFS RF; with either 1-computed tomography integration (CTII) into the electroanatomical mapping system or 2-intracardiac echo-facilitated 3D electroanatomical mapping (ICE3D).

2 | METHODS

A total of 53 patients with VAs originating at the LV PMs were identified from retrospective review of 352 consecutive patients (men 56%, age 49, range 23-57 years) with symptomatic sustained ventricular tachycardia (VT) (n = 106), non-sustained VT (n = 81), or PVCs (n = 165) referred to our institution for catheter ablation between January 2014 and January 2018. This study retrospectively included 53 patients with symptomatic, drug refractory VAs originated at the PMs. Patients with right ventricular (RV) PM VAs were not included in the study as we believe they should be addressed in a separate analysis, given their uniq"e anatomical and electrophysiological characteristics. The study was approved by the institutional review committee and all subjects gave written informed consent. Ablation technique was selected according to the operator preferences and available technologies. All antiarrhythmic drugs were discontinued for at least five half-lives before the study.

Structural heart disease and mitral valve function were assessed by echocardiography prior ablation. All patients underwent electrophysiological study and catheter ablation. Catheter ablation was performed under conscious sedation (N = 39) or general anesthesia (N = 14). Arrhythmia induction was attempted by programed electrical stimulation, with the addition of an isoproterenol infusion if necessary. Intravenous heparin was administered to maintain an activated clotting time of ≥300 seconds.

Patients were treated using three different approaches: (a) CRYO and CTII (EnSite® Velocity; St. Jude Medical Inc, St. Paul, MN, USA); (b) Non-CFS RF and CTII (EnSite® Velocity; St. Jude Medical Inc); and (c) CFS RF and ICE3D (CARTOSOUND/CARTO 3; Biosense Webster, Diamond Barr, CA, USA), as seen in Figure 1. In total three operators performed the ablation cases. Nevertheless, 91% of the procedures were performed by the same operator (N = 48).

In patients presenting spontaneous PMs VAs with variable QRS, focal mapping and ablation of the clinical arrhythmia may be difficult as multiple exit sites may be involved. In those cases, a point-by-point circumferential ablation at the base of the PM was performed to modify all possible exit sites of the clinical arrhythmia, as previously reported by Wo et al.[5]

Three segments were attributed to each PM: The apex, at the point of insertion of the chords (distal third of the PM); the body (middle portion of the PM); and the proximal third of the PM as the base, which is in continuity with the LV inferior wall. Catheter position, contact, and stability were assessed through intracardiac echocardiography (ICE), or ventriculography and 2D or 3D trans-esophageal ultrasound in cases where ICE was not available. Catheter stability was defined as the absence of back and forth movement of the catheter during energy delivery at the effective lesion site.

For patients treated without ICE3D, a multidetector computed tomography (MDCT) was obtained less than 15 days before catheter ablation (64-detector Phillips Brilliance; Phillips Medical Systems, Eindhoven, Netherlands). The cardiac MDCT image was then integrated into the electroanatomical mapping system.

Activation and pace mapping were performed in all cases. In cryoablation cases, activation points were collected using a decapolar catheter to avoid mapping with an 8 mm tip catheter. Pace mapping criteria was defined by a score determined from the R/S ratio and fine notching of the QRS in the 12-lead ECG (perfect pace mapping = 24 points), as previously reported.[3]

Energy was delivered at myocardial sites exhibiting the earliest bipolar activity or local unipolar QS pattern or at a Purkinje network with an early activity preceding the QRS onset for ≥25 milliseconds during the VA at pace-mapping areas exhibiting QRS score ≥20. Ablation was performed with either a 9-Fr/8-mm cryoablation catheter (Freezor MAX 3; Medtronic, Inc, Minneapolis, MN, USA) through a transeptal approach, using a 15 Fr steerable sheath (Flex Cath Advance, St. Jude Medical Inc) (Figure 2); a 4-mm open-irrigated Non-CFS RF ablation catheter (Therapy Cool; St. Jude Medical Inc.); or a 3.5-mm open-irrigated CFS RF ablation catheter (Thermocool Smart Touch SF; Biosense Webster) through a transaortic approach (Figure 3). If the ablation catheter was unstable and contact was limited, a transseptal and transmitral access was performed. When a reduction in the incidence of VT or PVCs was observed cryo-energy was delivered for up to 240 seconds with two freeze-thaw-freeze cycles and RF was delivered for up to 90 seconds, with two posterior 45 seconds consolidation lesions at the same area; otherwise, energy delivery was terminated, and the catheter was repositioned.

The end-point of catheter ablation was the elimination and non-inducibility of VAs during isoproterenol infusion (2-10 μg/min) and burst pacing from the RV to a cycle length as short as 300 milliseconds. Procedural acute success was defined as abolition of inducible or spontaneous ventricular arrhythmia.

2.1 | ECG analysis

Twelve-lead ECGs during the VAs and pace mapping were recorded digitally at a sweep speed of 100-200 mm/s in all patients for offline analysis. The QRS duration and axis, notching, and R to S transition in precordial leads (TZ) were measured with electronic callipers (EP-Work Mate 4.2 System; St. Jude Medical, Inc.) in all cases. An early R/S TZ was considered whenever the S wave presented equal or higher amplitude than the R wave between V1 and V3. If this occurred between V4 and V6, it was defined as late TZ.

2.2 | Follow-up

All patients were monitored continuously for 24 hours after the ablation procedure. Electrocardiography and echocardiography were performed before discharge and during follow-up. Information was obtained from direct evaluation in the arrhythmia clinic. Patients underwent 24-hours Holter monitoring and baseline electrocardiography before and 1, 3, and 6 months after the procedure. Successful long-term catheter ablation was

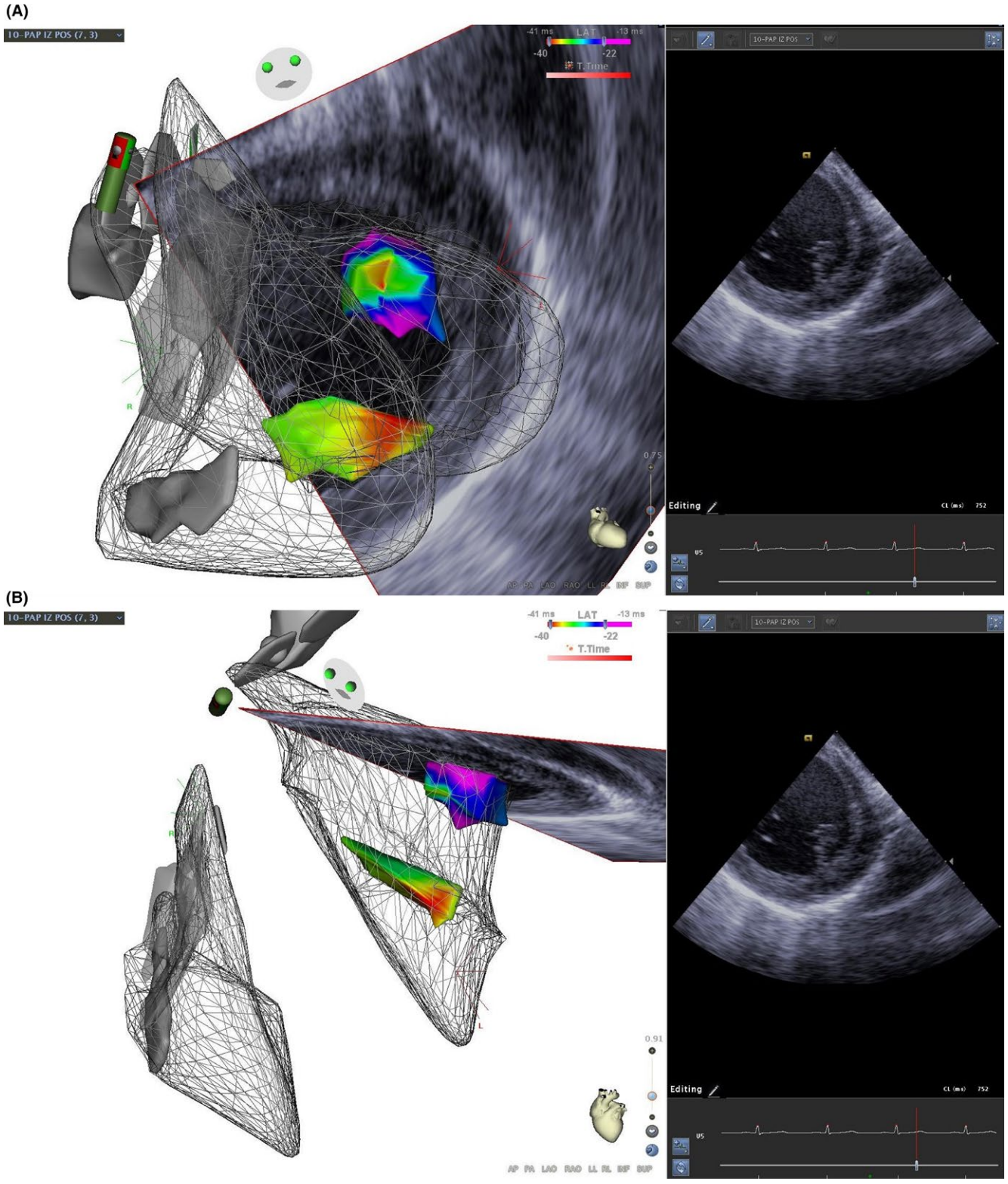


FIGURE 1 Lateral (A) view and upper (B) view of the ICE3D of both right and left ventricles (mesh). The activation map is limited to each LV PM and corresponds to the earliest activation site of the clinical arrhythmia in a patient exhibiting both ALPM and PMPM PVCs

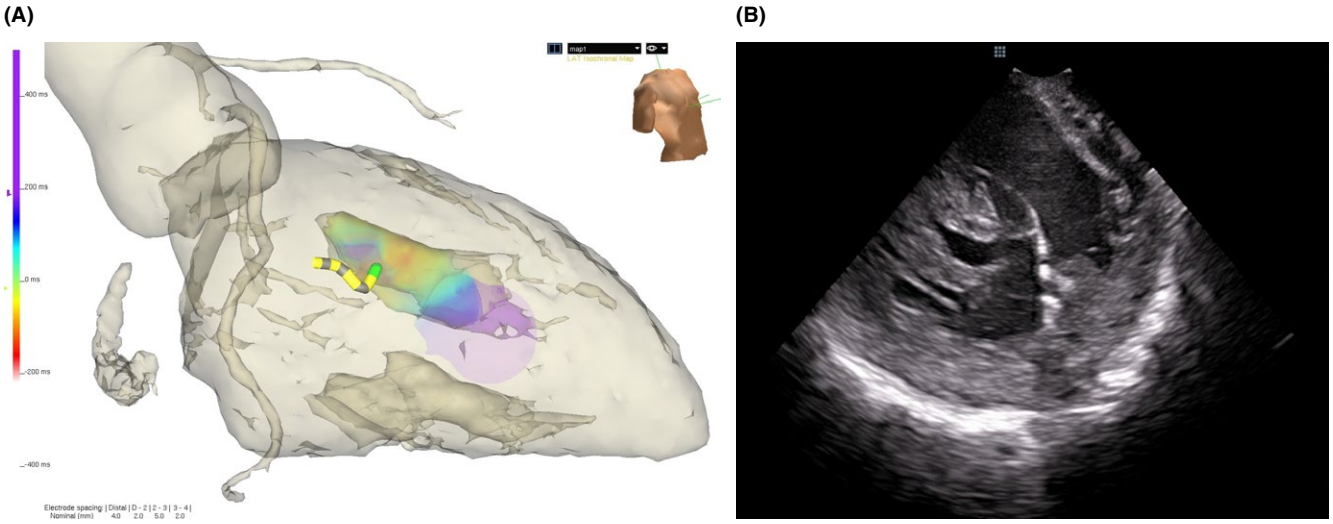


FIGURE 2 (A) Cardiac MDCT integration into the mapping system. An activation map demonstrates the earliest activation of the clinical arrhythmia at the body of the ALPM. The cryo-catheter is positioned at the effective lesion site. (B) ICE visualization of the cryo-catheter

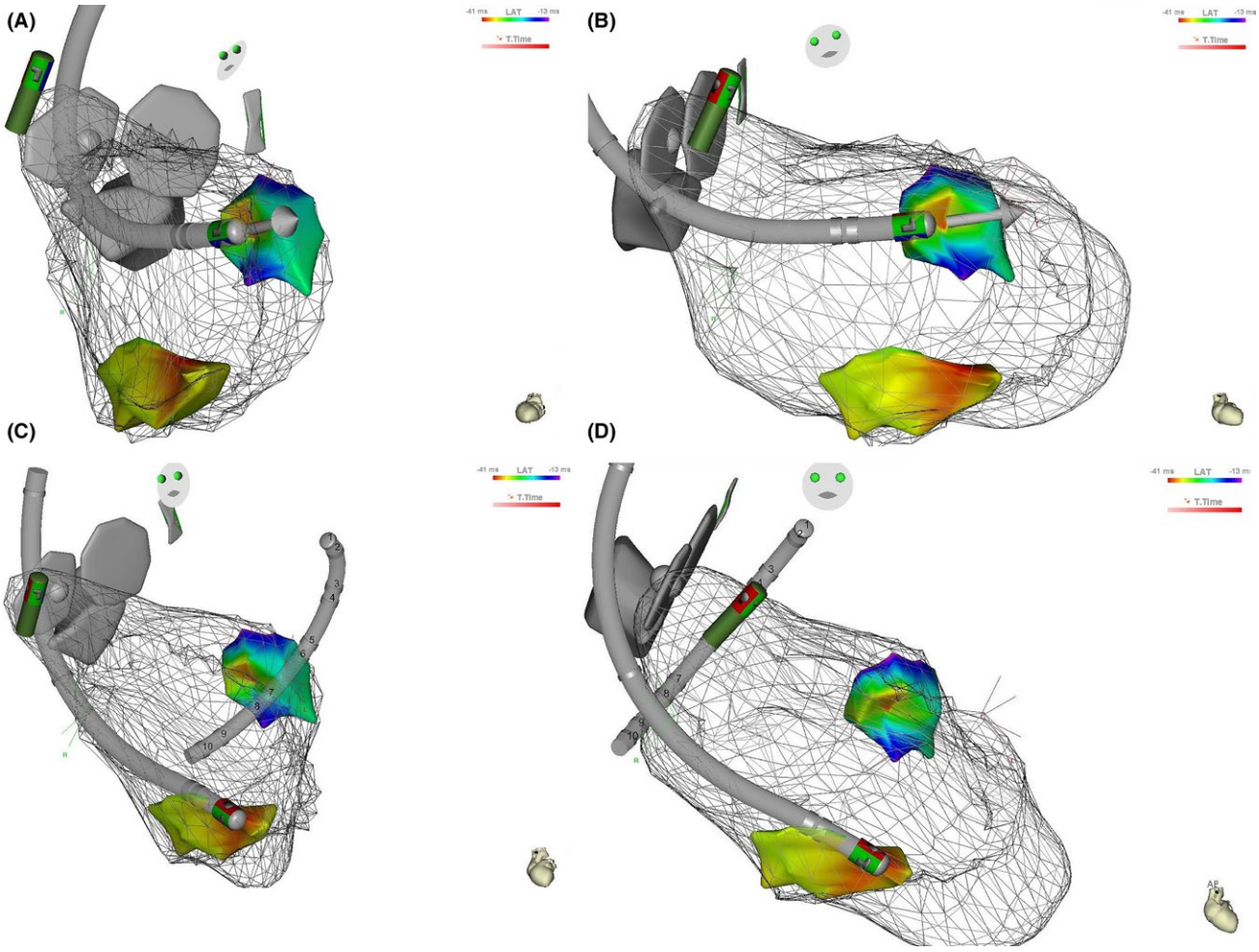


FIGURE 3 (A) Left anterior and (B) right anterior oblique view of the ICE3D map, showing the CFS-RF catheter placed at the effective lesion site (ALPM Apex), through a trans-aortic approach. Same patient, (C) Left anterior and (D) right anterior oblique view of the ICE3D map, showing the CFS-RF catheter placed at the effective lesion site (PMPM base). Intracardiac recordings of the (E) PMPM and (F: Left) ALPM clinical VA exhibiting a VEGM-QRS interval of 38 ms and 30 ms, respectively. Pace-mapping at the effective ablation site on the ALPM

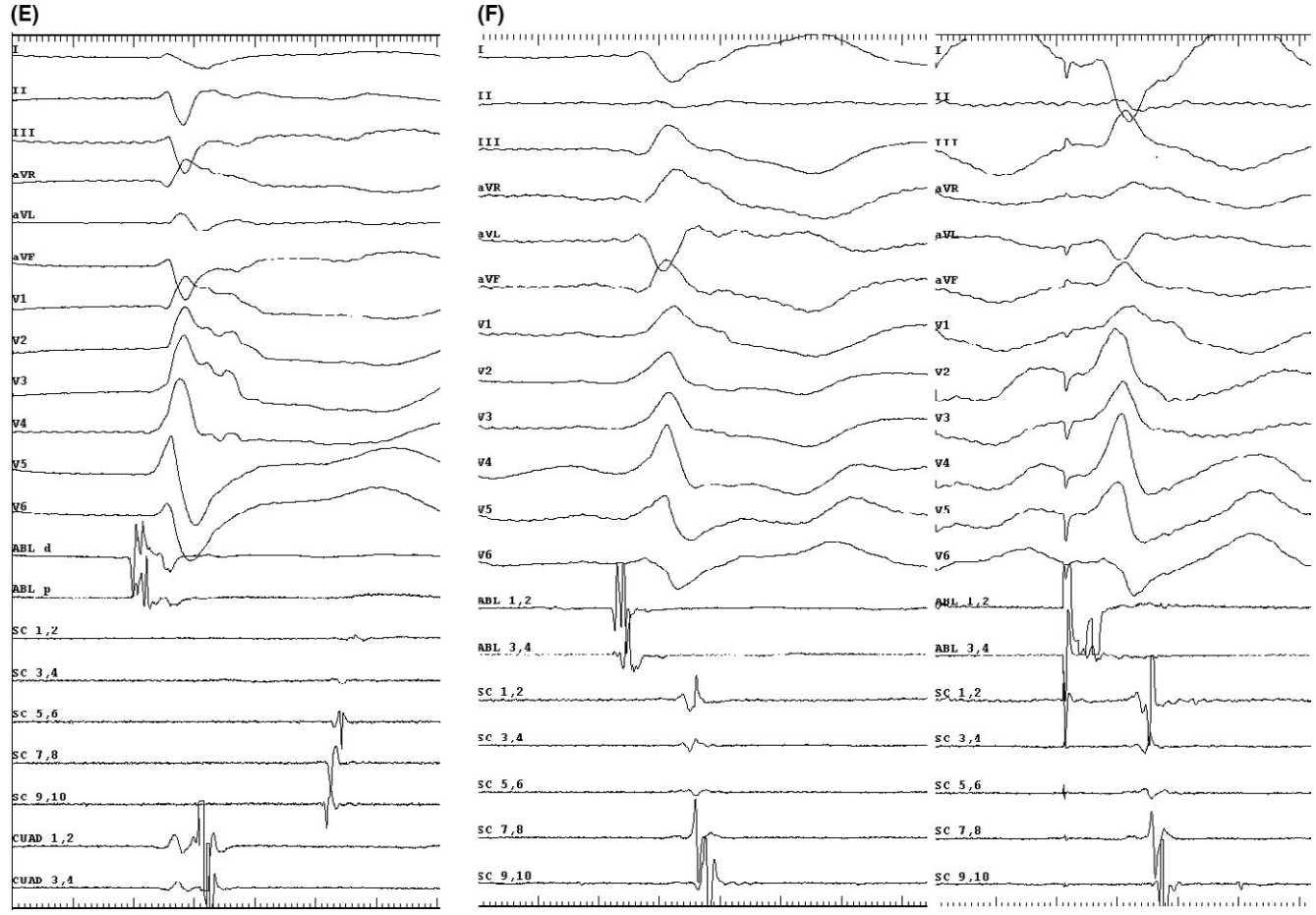


FIGURE 3 (Continued)

defined as a significant reduction (reduction of the clinical VA by ≥85%) or absence of the clinical arrhythmia at 1, 3, and 6 months follow-up.

2.3 | Statistical analysis

Continuous data are expressed as mean ± SD and categorical data are presented as absolute values and percentages. Statistical analysis was performed using the Rank sum test for non-normally distributed variables and categorical variables were compared using the χ^2 test.

Kaplan-Meier curves were generated and the comparison among the two groups was performed using the Log-rank test. A multivariate analysis was performed using Cox regression, to determine the variables associated with clinical VA recurrence. Data analysis was executed with the SPSS software version 20 (SPSS, IBM Corporation, Buenos Aires, Argentina). For all tests, a *P* value of 0.05 or lower was considered statistically significant.

3 | RESULTS

3.1 | Patient characteristics

Fifty-three (53) patients underwent PM VAs catheter ablation. The median age was 49 ± 17 years old and 18 (34%) were females. The LV ejection fraction (LVEF) median was 53 ± 11%. Mitral regurgitation (MR) was observed in 14 (26%) patients, of which 9 (17%) presented mitral valve prolapse. Severe MR was present in 5 patients. Myocardial disease was observed in 15 patients (73% ischemic; 20% dilated; and 13% hypertrophic cardiomyopathies). The most common clinical arrhythmia was PVC (45%) and the least frequent was VT (25%). Patients who presented spontaneous variable QRS morphologies (N = 4) were treated by circumferential ablation of the base of the PM (CRYO N = 2 / CFS RF N = 2).

Overall success and recurrence rates (N = 53 patients) were 92% and 30%, respectively. The population base line characteristics are sum up in Table 1.

3.2 | Papillary muscle characteristics

The PMPM had higher prevalence of clinical arrhythmias (83% PMPM VAs vs 17% ALPM VAs). The PM base was the most frequent site of origin of VAs (Base 63%; Body 25%; Apex 12%).

Purkinje potentials (PP) were observed in 35 (59%) patients. These PPs were present in 73% of VAs originating at the base of the PMs, while those VAs with origin at the body of the PMs only exhibited 33% prevalence, and none at the apex.

TABLE 1 Population general characteristics

Patients (N = 53)	Non-CF RF/CTII (N = 23)	CFS RF/ICE3D (N = 14)	CRYO/CTII (N = 16)	*P*
Age	48 ± 15 y/o	59 ± 17 y/o	41 ± 14 y/o	0.01
Male Gender	18 (78%)	9 (64%)	8 (50%)	0.2
AHT	5 (22%)	3 (21%)	1 (6%)	0.4
DBT	2 (9%)	3 (21%)	2 (12%)	0.5
LVEF	51 ± 12%	49 ± 13%	58 ± 4%	0.06
MVP	3 (13%)	2 (14%)	4 (24%)	0.6
MR	7 (30%)	3 (21%)	4 (24%)	0.8
MR Degree				
I- Mild	6 (86%)	0	2 (50%)	0.2
II- Moderate	0	1 (34%)	0	
III-Severe	1 (14%)	2 (66%)	2 (50%)	
Bivalvar MVP	0	1 (7%)	2 (12%)	0.2
MV Sx	1 (4%)	2 (14%)	0	0.2
SHD	12 (52%)	7 (50%)	11 (69%)	0.5
NSVT	7 (30%)	1 (34%)	8 (50%)	0.05
VT	4 (17%)	4 (29%)	5 (31%)	
PVC	12 (52%)	9 (64%)	3 (19%)	

Non-CFRF/CTII, no contact force sensing RF and cardiac tomography integration into the electroanatomical mapping system; CFS RF/ICE3D, contact force sensing RF and intracardiac echo-facilitated 3D electroanatomical mapping; CRYO/CTII, cryoablation and cardiac tomography integration into the electroanatomical mapping system; AHT, arterial hypertention; DBT, diabetes; LVEF, left ventricular ejection fraction; MVP, mitral valve prolapse; MR, mitral regurgitation; Bivalvar MVP, Bi-valvar MVP; MV Sx, prior mitral valve surgery; SHD, structural heart disease; NSVT, non-sustained ventricular tachycardia; VT, ventricular tachycardia; PVC, premature ventricular contractions.

3.3 | Procedural outcomes

A total of 59 PMVAs were observed (Single morphology N = 55; Variable QRS morphology N = 4). Termination of the arrhythmia was observed in 49 patients without further inducibility. Major complications were observed in one patient, who presented a non-surgical cardiac tamponade related to the transeptal puncture.

Patients treated with Non-CFS/CTII (n = 23) showed 83% acute success rate, while those treated with CFS RF/ICE3D (n = 14) and CRYO/CTII (n = 16) presented 100% acute success rate ($P = 0.03$). Catheter stability was achieved in all patients treated with CRYO/CTII; 50% in those treated with CFS RF/ICE3D; and only in 26% of patients in the Non-CFS RF/CTII group ($P = 0.001$). Average contact force at the PM base was 18 ± 5 g, while the body and apex presented 8 ± 3 and 4 ± 2 g, respectively. Incidence of multiple VAs morphologies during energy delivery (pro-arrhythmia) was 78% for RF, and 0% for CRYO/CTII ($P = 0.001$).

There were no differences between groups regarding ablation end-points such as VEGM-QRS interval >25 milliseconds and pace-mapping score in patients treated with focal ablation, as seen in Table 2.

The use of conscious sedation did not affect ablation outcomes when compared to general anesthesia, as observed in Table 4.

3.4 | Follow-up outcomes

Follow-up results are summed up in Table 2. There was no increase in the incidence of mitral valve regurgitation, or an increase of MR severity after ablation, using either method.

Clinical VA recurrence was 48% (n = 11) for those treated with Non-CFS RF/CTII; 19% (n = 3) for CRYO/CTII; and 7% (n = 1) for CFS RF/ICE3D ($P = 0.02$). A subgroup analysis showed no significant differences regarding recurrence between CRYO/CTII and CFS RF/ICE3D (19% vs 7%; $P = 0.6$). One patient from the cryoablation group showed delayed success, with Holter burden reduction from 50% to <5% after 6 months. Figure 4 shows the free from VAs survival curves.

The use of antiarrhythmic drugs and Holter burden were reduced (93% vs 29%; $P = 0.05$ and 22 ± 9% vs 4 ± 7%; $P = 0.006$, respectively) after ablation, with the use of CFS RF/ICE3D. Holter burden and anti-arrhythmic drugs reduction for CRYO/CTII were 14 ± 10 to 3 ± 3% ($P = 0.06$) and 19% to 6% ($P = 0.09$), respectively. The use of anti-arrhythmic drugs after Non-CFS/CTII ablation showed a non-significant reduction (48% to 35%; $P = 0.1$) and Holter burden was reduced from 25 ± 10 to 14 ± 12% ($P = 0.05$), without achieving a clinical reduction of more than 85%.

TABLE 2 Procedure characteristics

LV PMs (N = 59)	Non-CFS RF/ CTII (N = 23)	CFS RF/ICE3D (N = 18)	CRYO/CTII (N = 18)	*P*
Catheter stability	6 (26%)	9 (50%)	18 (100%)	<0.0001
Pro-arrhythmia	18 (78%)	14 (78%)	0 (0%)	<0.0001
VEGM-QRS	32.4 ± 5.6 ms	33.2 ± 4.7 ms	30.2 ± 12.4 ms	1
PMAP score	22 (IQR 22-24)	22 (IQR 22-24)	22 (IQR 22-24)	0.7
Effective lesion location				
I- PM Apex	2 (9%)	1 (6%)	2 (11%)	0.1
II- PM Body	2 (9%)	8 (44%)	5 (28%)	0.1
III- PM Base	19 (82%)	9 (50%)	11 (61%)	0.1
CRYO dose (seg.)	N/A	N/A	766.7 ± 321.8	N/A
RF Dose (seg.)	361.6 ± 182.3	915 ± 653.1	N/A	N/A
Success	19 (83%)	18 (100%)	18 (100%)	0.03
Patients (N = 53)	**Non-CFS RF CTII (N = 23)**	**CFS RF/ICE3D (N = 14)**	**CRYO/CTII (N = 16)**	***P***
Procedure duration	139 ± 39.7 min	164.5 ± 58 min	131.3 ± 26.2 min	0.3
Fluoroscopy time	14.2 ± 4.6 min	6.2 ± 1.5 min	10.7 ± 4.2 min	<0.0001
Transeptal access	10 (44%)	8 (57%)	16 (100%)	0.001
Minor complications	0	2 (12%)	0	0.1
Major Complications	1 (4%)	0	0	0.8
Prior ablation	0	2 (14%)	0	0.06
Circumferential	0	3 (21%)	2 (13%)	0.08
Focal	23 (100%)	12 (86%)	14 (88%)	0.2
Recurrence	11 (48%)	1 (7%)	3 (19%)	0.0172
FUP time (Mo)	12 ± 10	15 ± 18	13 ± 7.5	0.5307

LV PMs, papillary muscles of the left ventricle; Non-CFS RF/CTII, no contact force sensing RF and cardiac tomography integration into the electroanatomical mapping system; CFS RF/ICE3D, contact force sensing RF and intracardiac echo-facilitated 3D electroanatomical mapping; CRYO/CTII, cryoablation and cardiac tomography integration into the electroanatomical mapping system; Pro-arrhythmia, variable QRS morphology arrhythmias during energy delivery; VEGM-QRS, ventricular electrogram/presystolic electrogram to QRS interval; PMAP score, pace-mapping score; CRYO dose, cryo-energy dose; RF dose, radiofrequency dose; Success, elimination of the clinical arrhythmia; Prior ablation, previously failed catheter ablation of the clinical arrhythmia; Circumferential, circumferential point-by-point catheter ablation; Focal, focal energy delivery; Recurrence, recurrence of the clinical arrhythmia; FUP-time, follow-up time in months.

3.5 | ECG analysis

Mean QRS duration of the clinical VA was 156 ± 15 milliseconds. Clinical arrhythmias with an R > r` pattern in lead V1 were the most frequent among patients with single morphology QRS (79% vs 11%). VAs with early precordial TZ were more frequently seen at the base of PMPM, while late precordial TZ was observed with VAs originating at the apex of the PMs. Arrhythmias originating at the PMPM showed a superior axis in 88% of cases, and 77% of VAs with origin at the ALPM presented an inferior axis. Electrocardiographic characteristics of single morphology PM VAs (N = 55) are summed up in Table 3.

3.6 | Univariate and multivariate analysis

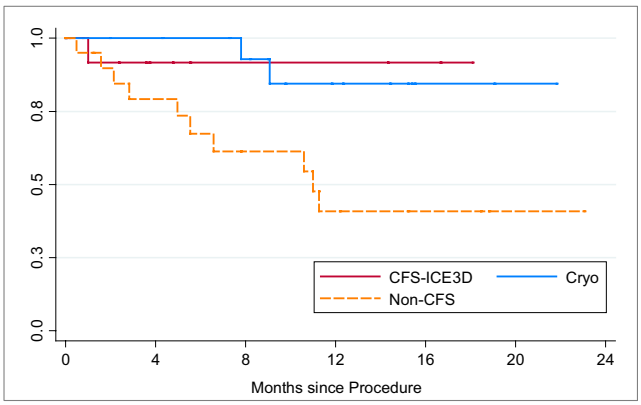
Univariate and multivariate analysis were performed using Cox regression, to predict which variable was associated with an increased risk of clinical VA recurrence. The use of Non-CFS RF catheters was the sole variable associated with a higher risk of recurrence, as seen in Table 4.

4 | DISCUSSION

4.1 | Main findings

This study demonstrated that: (a) Regarding overall success, both CRYO/CTII and CFS RF/ICE3D approaches were equally effective, while the use on Non-CFS RF/CTII was associated with a 4.6-fold increase risk of recurrence of the clinical arrhythmia. The most effective approach regarding reduction of anti-arrhythmic drug use and Holter burden after catheter ablation was CFS RF/ICE3D. (b) Regarding catheter stability and possible pro-arrhythmic effect: All patients treated with CRYO/CTII presented stable contact

and pro-arrhythmia was non-existent during cryoablation, while almost 80% of patients treated with RF showed variable QRS VAs during energy delivery, which account for a pro-arrhythmic effect of RF. Although catheter stability was significantly improved with the use of CFS RF/ICE3D, it was only achieved in 50% of patients. We believe this was primarily thanks to ICE3D rather than contact force sensing by providing better anatomical landmarks, thus improving catheter navigation. Stable contact may not be the sole determinant for successful ablation. (c) Regarding contact force sensing: this was higher at the base of the PMs, as the catheter tends to wedge at this location, in contrast to non-basal aspects of the PM, where the catheter tends perform a brushing-like movement as good contact is harder to obtain. Cryo-ablation may be a suitable alternative as catheter-adherence may overcome contact limitations at these locations.



Interval	0 4	4 8	8 12	12 16	16 20	20 24
CFS-ICE3D	14	6	4	2	0	0
Non-CFS	20	14	9	6	3	1
Cryo	17	16	13	8	3	1

FIGURE 4 Patients free from ventricular arrhythmias after catheter ablation

4.2 | Papillary muscles' electrophysiological characteristics

The prevalence of spontaneous VAs with variable QRS was very low in this cohort of patients, which is inconsistent with the literature. The base of the posteromedial PM was the most arrhythmogenic site of origin. The most frequent QRS pattern was R < r'. Early precordial TZ was more frequently observed in VAs originating at the base of the PM, while late TZ was associated with a more distal (chordae insertion site) origin at the PM. These results may suggest that PM VAs may not exit exclusively through the base. Arrhythmias with superior or inferior QRS axis were not solely observed at the ALPM or PMPM VAs, respectively. This could be consistent with the presence of intermuscular connections, responsible for conducting the impulse from the origin at one PM and exiting through the other, which may explain shifting exit sites and QRS axis. These muscular connections have already been demonstrated.[6]

4.3 | Prior studies

It has been reported that almost half of the patients with PM VAs may present with variable QRS morphologies.[7] In this scenario, recurrence after RF ablation can be as high as 60%.[8,9] Spontaneous variable QRS morphologies may respond to preferential conduction to multiple breakout sites, due to an anisotropic mechanism given the complexity of the myocardial strands distribution between the base and apex of the PM.[10,11] Ablation at sites with excellent pace mapping can be unsuccessful, also suggesting that the

TABLE 3 Electrocardiographic and electrophysiologic characteristics

	ALPM			PMPM		
LV PM VAs N = 55	Non-Basal (N = 4)	Basal (N = 5)	*P*	Non-Basal (N = 16)	Basal (N = 30)	*P*
QRSD (ms)	153.8 ± 24	160.4 ± 17.2	0.6	158.1 ± 17.6	152.6 ± 13.9	0.4
QRSM R > r' V1	4 (100%)	4 (80%)	0.6	12 (75%)	25 (83.3%)	0.5
QRSM r < R' V1	0 (0%)	1 (20%)	1	4 (25%)	5 (16.7%)	0.7
TZ	V5 (IQR V5-V6)	V4 (IQR V4-V5)	0.03	V5 (IQR V4-V6)	V4 (IQR V3-V4)	0.05
Negative Lead I	4 (100%)	4 (80%)	1	0	2 (7%)	0.5
Positive Lead I	0 (0%)	1 (20%)	1	0	28 (93%)	0.5
PPs	1 (25%)	3 (60%)	0.5	6 (37.5%)	22 (73.3%)	0.03
PP Amp (mV)	0.4 ± 0.1	1 ± 0.2	0.5	0.4 ± 0.2	0.7 ± 0.2	0.005
VEGM Amp (mV)	0.3 ± 0.1	1 ± 0.6	0.1	0.5 ± 0.2	0.9 ± 0.3	<0.001
QRS notching	2 (50%)	2 (40%)	1	6 (37.5%)	13 (43.3%)	0.8

LV PM VAs, papillary muscles of the left ventricle with single QRS norphology; ALPM, anterolateral PM; PMPM, postero-medial PM; Non-basal, foci located at the body or apex of the PM; Basal, foci located at the base of the PM; QRSD, duration of the QRS milliseconds; QRSM R > r' V1, QRS morphology exhibiting an Rsr' complex in lead V1; QRSM r<R' V1, QRS morphology exhibiting an rSR' complex in lead V1; TZ, precordial lead at which the QRS begins to exhibit an S wave of equal or greater amplitude than the R wave; PPs, pre-potentials; PP Amp, amplitude of the PP in millivolts; VEGM Amp, amplitude of the ventricular electrogram in millivolts.

TABLE 4 Univariate and multivariate analysis

	Univariate analysis		Multivariate analysis	
Variable	**HR**	***P***	**HR**	***P***
Gender	1.03 (0.3-3.4)	0.9	1.4 (0.4-5)	0.5
Age	1.0 (0.9-1.0)	0.3	0.9 (0.9-1.0)	0.2
LVEF	0.9 (0.9-1.0)	0.7		N/S
CFS RF/ICE3D	0.2 (0.02-1.5)	0.1		N/S
Non-CFS RF/CTII	4 (1.3-13)	0.02	4.6 (1.4-15)	0.01
CRYO/CTII	0.6 (0.2-2)	0.3		N/S
ICE	0.8 (0.3-2)	0.6		N/S
SHD	0.8 (0.3-1.8)	0.7		N/S
Transeptal	0.6 (0.2-8)	0.4		N/S
MVP	1.2 (0.4-3.7)	0.7		N/S
Conscious Sedation	0.36 (0.08-1.6)	0.2		N/S

LVEF, left ventricular ejection fraction; CFS RF/ICE3D, contact force sensing radiofrequency ablation and intracardiac echo-facilitated 3D electroanatomical mapping; Non-CFS RF/CTII, non-contact force sensing ablation and cardiac tomography integration into the electroanatomical mapping system; CRYO/CTII, cryoablation and cardiac tomography integration into the electroanatomical mapping system; ICE, intracardiac echocardiography; SHD, structural heart disease; Transeptal, transeptal access; MVP, mitral valve prolapse.

site of VA origin may be located away from the breakout site.[9-12] Purkinje potentials can be observed in 45% of PM VAs.[3] They are frequently recorded at the base of the PMs at the Purkinje-fibber-muscular interface, and rarely at a distal aspect, suggesting that the Purkinje network may not extend further toward the chordae insertion site and that VAs may arise from the myocardium itself.[3] Distal Purkinje fibbers may be involved in triggering or maintaining PM VAs.[5,10,11,13] The latter is supported by a recent description of PM fascicular VT (PM-FVT), which shares a similar QRS morphology of FVT,[6] presenting RBBB with r < R' configuration. Monomorphic ventricular PVCs originating from the PMs have been found to initiate idiopathic ventricular fibrillation or polymorphic VT, either in structurally normal hearts or in patients with bileaflet mitral valve prolapse.[14-17]

Our previous studies showed that cryoablation of single morphology VAs with origin at the PMs of the LV was more effective than Non-CFS RF/CTII.[3,4] These results remain the same in the current study, and the enhanced result of RF were attributed to the addition of CFS catheters and specially to the use of intracardiac echo-facilitated 3D electroanatomical mapping. Cryoablation has been reported as a safe alternative. Cryothermal safety profile is attributed to the mechanism of tissue destruction. Histology of chronic lesions shows well-demarcated lesions with minimal tissue disruption and preserved underlying architecture.[3] Catheter stabilization is achieved due to catheter-tissue adherence after reaching temperatures of −80°C.

Intracardiac Echography is of critical importance when performing PM VA ablation. A strong association was detected between the use of ICE3D and success of the procedure. The risk of recurrence of VT can be 20 times higher in patients who undergo ablation without ICE3D.[18]

4.4 | Study limitations

This is not a randomized trial comparing different energy sources or mapping techniques for catheter ablation of PM related arrhythmias. Patients were treated depending on the available technology, as contact force catheters or ICE3D were not available at early stages. Cryoablation was not implemented together with CARTOSOUND due to higher costs. These may have accounted for a selection bias.

Ablation outcomes may have been influenced by operator experience and learning curve, although all operators have previous experience with PM catheter ablation before this study.

We defined stability as the absence of back and forth movement (brushing-like motion) of the catheter. Although cryo-catheter adherence does represent a technical advantage, in this scenario it did not affect outcomes. We believe that ICE3D does improve stability, although RF will not allow for catheter adherence. These results were conditioned by our definition of catheter stability.

The small number of patients treated using a circumferential catheter ablation approach does not allow to make any assumption regarding outcomes between the latter and focal ablation.

5 | CONCLUSIONS

The use of Non-CFS RF/CTII was associated with a 4.6-fold increase risk of recurrence after catheter ablation of LV PM VAs. Ablation with either CFS RF/ICE3D or CRYO/CTII showed high acute success rates and low recurrence rates during follow-up and were safe alternatives. Cryoablation provided stable contact and was less arrhythmogenic.

ACKNOWLEDGEMENTS

The authors would like to acknowledge Laura Gutierrez, from the Buenos Aires Cardiovascular Institute.

CONFLICT OF INTERESTS

Authors declare no conflict of interests for this article.

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How to cite this article: Rivera S, Tomas L, Ricapito MdlP, et al. Updated results on catheter ablation of ventricular arrhythmias arising from the papillary muscles of the left ventricle. *J Arrhythmia*. 2019;35:99–108. https://doi.org/10.1002/joa3.12137