ORIGINAL ARTICLE

Arrhythmias Originating in Left Ventricular Papillary Muscles: Clinical Characteristics, Multislice Imaging and Catheter Ablation

Arritmias originadas en los músculos papilares del ventrículo Izquierdo: características clínicas, multi-imágenes y ablación por catéter

SANTIAGO RIVERA, GASTÓN ALBINA, LEANDRO TOMAS, MARÍA DE LA PAZ RICAPITO, IGNACIO MONDRAGÓN, MILAGROS CARO, MARCELO REINOSO, DIEGO BELARDI, ALBERTO GINIGER, FERNANDO SCAZZUSO

ABSTRACT

Background: Ventricular arrhythmias can arise from the left ventricular papillary muscles.
Objectives: The aim of this study was to describe the most relevant features of this type of ventricular arrhythmias and to compare outcomes with either cryoenergy or radiofrequency catheter ablation.
Methods: Forty-two patients undergoing catheter ablation for ventricular arrhythmias originating in the left ventricular papillary muscles were included in the study. Mean age was 47±16 years, 70% were men, and median ejection fraction was 55±11%. Ventricular arrhythmias were localized using three-dimensional mapping, multislice computed tomography and intracardiac echocardiography, with arrhythmia foci mapped at either the anterolateral or posteromedial papillary muscles. Ablation was performed using an 8-mm focal cryoablation catheter or a 4mm open-irrigated radiofrequency ablation catheter.
Results: All clinical ventricular arrhythmias exhibited a right bundle branch block pattern, with mean QRS duration of 150±13 ms and R>r' pattern in the left ventricle in 71.4% of cases. Acute success rate was 100% for cryoablation (n=18) and 83% for radiofrequency ablation (n=20) (p=0.06). Ventricular arrhythmia recurrence at 12 months was 4% for cryoablation and 46% for radiofrequency ablation (p=0.02). Use of radiofrequency ablation (HR 0.2; P=0.04) and lack of intracardiac echocardiography (HR 0.1; p=0.01) were associated with higher risk of recurrence.
Conclusions: Right bundle branch block morphology with left ventricular R>r' pattern and QRS duration >135 milliseconds are the most frequent clinical characteristics of these ventricular arrhythmias Use of cryoablation and intracardiac echocardiography were associated with lower recurrence rates, while radiofrequency ablation was associated with 20% increase of clinical arrhythmia recurrence after ablation.

Key words: Arrhythmias, Cardiac - Cryosurgery - Echocardiography

RESUMEN

Introducción: Las arritmias ventriculares pueden originarse en los músculos papilares (MPs) del ventrículo izquierdo (VI).
Objetivos: describir sus características clínicas más relevantes y comparar resultados de la ablación por catéter utilizando crioenergía (CRY) o radiofrecuencia (RF).
Métodos: Cuarenta y siete pacientes (47 ± 16 años; 70% sexo masculino; Fracción de eyección 55 ± 11%) con arritmias originadas en los MPs del VI, tratados mediante ablación por catéter fueron incluidos. Las arritmias clínicas fueron localizadas utilizando sistemas de mapeo 3D, tomografía cardiaca multicorte y ecografía intracardiaca (ICE). La ablación fue efectuada utilizando un catéter de CRY focal de 8mm o un catéter de ablación con irrigación abierta de 4mm.
Resultados: Las arritmias exhibieron una morfología de bloqueo de rama derecha (100%), con una duración media del QRS de 150±13ms y patrón R>r' en VI en el 71,4% de los casos. La tasa de éxito agudo fue de 100% para CRY (n=18) y 83% para RF (n=20) (p=0.06). La recurrencia a 12 meses fue 4% para CRY y 46% para RF (p=0.02). Las variables asociadas con mayor riesgo de recurrencia fueron el uso de RF (HR 0.2; P=0.04) y la falta de ICE (HR 0.1; p=0.01).
Conclusiones: La morfología de bloqueo de rama derecha con patrón R>r' y duración del QRS >135mseg representan las características más frecuentes. El uso de ICE y CRY se asoció a una menor tasa de recurrencia. El uso de RF presento un incremento del riesgo de recurrencia del 20%.

Palabras clave: Arritmias Cardíacas - Criocirugía - Ecocardiografía

Rev Argent Cardiol 2015;85:425-433. http://dx.doi.org/10.7775/rac.v85.i5.10249

Received: 07-13-2017 - *Accepted:* 09-08-2017

Address for reprints: Santiago Rivera - Av. Libertador 6302 - C1428DCO Buenos Aires, Argentina. Tel: (011) 4787-7500 - Fax: 5411 4787-7500 - e-mail: riv.santiago@gmail.com

Instituto Cardiovascular de Buenos Aires (ICBA). Buenos Aires, Argentina.

Abbreviations

AF	Atrial fibrillation	**PM**	Papillary muscles
ALPM	Anterolateral papillary muscle	**PMPM**	Posteromedial papillary muscle
CRY	Cryoenergy	**RF**	Radiofrequency
ICE	Intracardiac echocardiography	**SM**	Stimulation maps
MDCT	Multi-detector computed tomography	**VA**	Ventricular arrhythmias
MR	Mitral regurgitation	**VES**	Ventricular extrasystoles
MVP	Mitral valve prolapse	**VT**	Ventricular tachycardia

INTRODUCTION

Left ventricular papillary muscles (PM) frequently originate ventricular arrhythmias (VA) either in the presence or absence of structural cardiomyopathy. (1-3) These ventricular arrhythmias, may even trigger ventricular fibrillation and sudden death, (4, 5) and may also arise from PM in the right ventricle (6, 7) They are sometimes associated with mitral valve prolapse (MVP), whose arrhythmogenic mechanism is still nor completely understood. (8) Catheter ablation has been reported as a safe and effective therapeutic method to treat these arrhythmias, though the outcomes are very heterogeneous, reaching up to 58% recurrence rates. (2, 3)

This study is aimed: a) To describe the clinical and electrophysiological characteristics of patients with ventricular arrhythmias originating in the PM and their association with mitral regurgitation (MR) and MVP; and b) to report catheter ablation results comparing different types of energy sources [cryoenergy (CRY) vs. radiofrequency (RF)] and the use if intracardiac echocardiography (ICE).

METHODS

The study population consisted of 248 consecutive patients (mean age 55±15 years, 71% male sex), with symptomatic VA, originating in the right ventricular outflow tract (46%), associated to ventricular scar (19%), PM (17%), left ventricular summit (4%), aorto-mitral continuity (4%), aortic cusps (4%), interventricular septum (4%), mitral annulus (2%), right ventricular PM (1%) and fascicular (1%), refractory to antiarrhythmic drug therapy (64%) or who refused pharmacological treatment (36%). These patients were retrospectively referred to catheter ablation for ventricular extrasystoles (VES) (45%) or ventricular tachycardia (VT) (55%) at the Instituto Cardiovascular de Buenos Aires (ICBA) between January 2014 and January 2017. All the patients signed an informed consent before entering the study. The antiarrhythmic agents [betablockers (15%), amiodarone (7%), and 1C antiarrhythmic drugs (5%)] were discontinued for at least 5 half-lives before the procedure.

In all cases, clinical and electrocardiographic data were analyzed to establish MVP and the most frequent electrocardiographic characteristics for this type of arrhythmias.

Multislice images

Multi-detector computed tomography (MDCT) was performed with a Phillips Brillance 64-slice scanner (Phillips Medical Systems) 15 days before the ablation.

Non-ionic contrast material (Optiray 350 mg/ml) was used and images were acquired at a slice width of 0.9 mm. Electrocardiographic-gated images at phase 75% of the cardiac cycle were prospectively acquired to eliminate artifacts generated by heart motion and reduce the radiation dose.

Images obtained by MDCT were integrated to the electro-anatomic mapping system using ICE or three-dimensional (3D) color Doppler transesophageal echocardiography (Figure 1).

Catheter ablation

A decapolar catheter was introduced in the coronary sinus and another in the right ventricular apex. Bipolar electrograms were recorded with an open-irrigated 4 mm-tip quadripolar ablation catheter (Therapy Cool, St. Jude Medical) with filtering between 30 and 500 Hz. Transseptal and transmitral (64%) or aortic-retrograde (36%) access routes were used, with intravenous unfractionated sodium heparin administration to keep an activated coagulation time >300 seconds. Activation and endocardial voltage mapping was performed using the EnSite Velocity (St. Jude Medical Inc.) or CARTO 3 (Biosense Webster INC, Diamond Bar, CA) systems. The primary endpoint was the suppression and non-inducibility of clinical arrhythmias. In cases where clinical arrhythmia was not observed spontaneously, programmed ventricular stimulation was attempted from the coronary sinus and from the right ventricular apex and outflow tract with 1, 2 and 3 extra-stimuli after an 8-beat stimulation train. Continuous isoproterenol infusion was used if necessary. Stimulation maps (SM) of the clinical arrhythmia were obtained in all cases. Stimulation mapping was performed during continuous stimulation at constant cycle duration of 600 milliseconds and amplitude of 1 mA above the diastolic threshold. Two criteria were used: 1) Compatible stimulated QRS in ≥ 11/12 leads, and 2) A defined score for the R/S ratio and QRS notches in the 12-lead ECG (Perfect SM=24 points). (9)

Stability was defined as absence of ablation catheter movement during energy delivery, assessed by ICE or fluoroscopy.

Energy sources

Both RF and CRY were used at the sites exhibiting premature bipolar activity (preceding QRS onset by ≥25 ms) or unipolar QS pattern, in areas displaying compatible QRS in ≥ 11/12 leads or a score ≥20. Focal ablation was effected with an 8 mm-tip cryoablation catheter (Freezor MAX 3, Medtronic, Inc, Minneapolis, MN) or an open-irrigated 4mm-tip quadripolar ablation catheter (Therapy Cool, St. Jude Medical). In cases treated with CRY, once the elimination of the clinical arrhythmia was confirmed, CRY was delivered for 240 ms, followed by two cycles of freeze-thaw-freeze. Conversely, CRY delivery was interrupted and the catheter was repositioned. In patients where RF was used, this was emitted during 90 seconds (40 Watts/43 degree) followed by two 45-second energy deliveries. The primary endpoint was the elimination and non-inducibility of the clinical

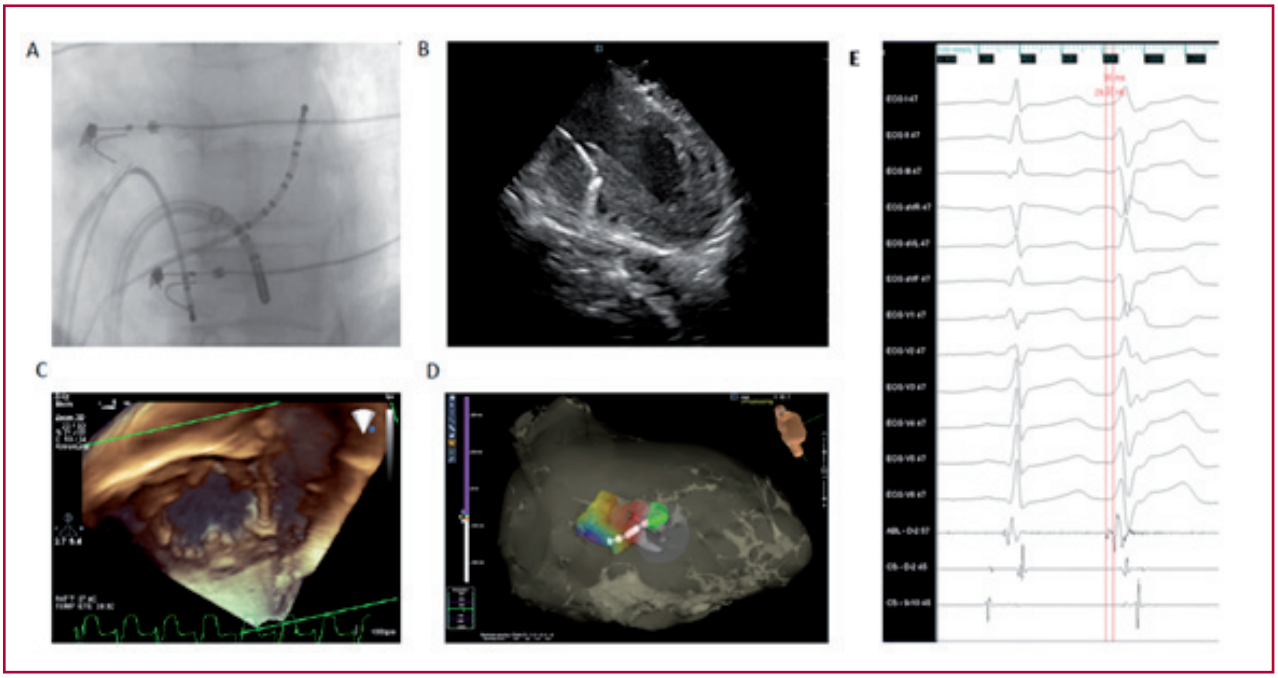

Fig. 1. A) Fluoroscopy showing cryoablation catheter located at the site of effective ablation, quadripolar catheter situated in the right ventricular apex, intracardiac echocardiography catheter (ICE) placed in the right ventricular outflow tract and multipolar catheter inside the coronary sinus. **B)** Intracardiac echocardiography view of focal cryoablation catheter directed towards the base of the posteromedial papillary muscle. **C)** Three-dimensional trans-esophageal echocardiography showing the cryoablation catheter contacting the lateral fascicle of the posteromedial papillary muscle, on the effective ablation site. **D)** Multi-detector computed tomography integration to the electro-anatomical mapping system and activation map of the posteromedial papillary muscle showing the premature activation site, corresponding to the origin of the ventricular arrhythmia (white area). **E)** Electrocardiographic characteristics of the arrhythmia originating at the base of the papillary muscle showing complete right bundle branch block with R>r'; premature R/S transition in V4, superior electrical axis, predominantly positive complex in lead I, and QRS width over 135 ms. The recording catheter situated at the origin of the arrhythmia shows the presence of double and fractionated electrograms, with 35 ms anticipation (VEGM-QRS) between the ventricular electrogram (VEGM) during the arrhythmia and QRS onset.

arrhythmia, both spontaneously as with programmed ventricular stimulation with cycles of up to 300 ms or isoproterenol infusion (2-20 μg/min).

Intracardiac echocardiography

A two-dimensional ICE catheter (View Flex, St. Jude Medical Inc.) was advanced towards the right atrium and then to the right ventricular outflow tract, to visualize the left ventricular papillary muscles. Three segments were allocated to each PM, specifying the origin of the arrhythmia: the apex, corresponding to the insertion of chordae tendineae, the body, representing the middle third of the PM and the proximal third, in contact with the left ventricular wall, corresponding to the base of the PM. In case of circumferential isolation of the PM, the position of the catheter near the base of the muscle was confirmed by ICE (Figure 2). In the event of no ICE availability, a ventriculogram and/or color Doppler transesophageal echocardiography was performed to establish the corresponding segment.

Continuous ICE monitoring was accomplished with special attention to mitral valve regurgitation due to PM dysfunction or rupture, or pericardial effusion. This method was also used to determine catheter position, contact, stability, and ablation lesion. In case of uncertainty regarding catheter position, this were corroborated by 3D transesophageal echocardiography.

Follow-up

All patients were continuously monitored for 24 hours after the ablation procedure. Twelve-lead ECG was performed to all patients prior to discharge. Follow-up information was obtained by direct evaluation at our arrhythmia and cardiac device clinic. All symptomatic patients underwent 24-hour Holter monitoring to establish the cause of symptoms. Long-term success of catheter ablation was defined as ≥50% absence or reduction of clinical arrhythmia at 1, 3 and 6-month follow-up.

Statistical analysis

Continuous variables were expressed as mean or median and discrete variables in numbers and percentages with their corresponding standard deviation and interquartile range, according to sample distribution. Discrete variables were compared with the chi-square test or Fisher's exact test and continuous variables with Student's t test or the Mann-Whitney test, depending on sample distribution. Statistical significance was established for $p=0.05$.

Ethical considerations

The study was evaluated and approved by the institutional Ethics Committee. All patients signed an informed consent before entering the study.

RESULTS

A total of 42 patients with arrhythmias originating in the left ventricular PM were included in the study. Mean age was 47±16 years, 70% were men, 17.5% had hypertension and 10% were diabetic.

General characteristics:

Mean ejection fraction (EF) was 55±11% (left ventricular diastolic diameter: 54±8 mm; left ventricular systolic diameter: 38±10 mm). Among selected patients, 17.5% had MVP, 32% MR (2 patients presented a severe degree of regurgitation involving both leaflets, 37.5% presented structural cardiomyopathy (ischemic in 7 patients, hypertensive in 2, dilated in 3 and MVP in 6 cases). Non-sustained ventricular tachycardia was the most frequent clinical presentation (42%) while 40% presented VES and only 8% VT.

Electrophysiological characteristics

Right bundle branch block pattern was observed in all the cases. The most prevalent morphologies were Rsr', RSr' and R type in lead V1 (71.4%), where the initial R wave was more predominant than the r' wave (R >r'). In patients presenting r<R' pattern (28.6%), 58% was distributed at the PM base, 42% in the body and 0% in the apex. Mean QRS duration was 150±13 ms. Eighty-five percent of arrhythmias were identified in the posteromedial papillary muscle (PMPM) and the most frequent site of origin was the base (67%), followed by the body (21%) and finally the apex (12%). The presence of pre-systolic potential was 65%, with decreasing intensity from base to apex (base: 69%, body: 57% and apex: 0%).

Catheter ablation

The mean interval between ventricular electrogram (VEGM) and QRS was 34±5 ms and the median stimulation score was 22. Fifty-five percent of procedures were performed using ICE and CRY was used in 45%. Mean fluoroscopy time was 13±5 min and total procedure time 139±39 min. Pro-arrhythmia was observed in 45% and the catheter was stabilized in 60% of cases. Primary success rate was 90%, with an annual recurrence of 32%. In two cases, circumferential cryoisolation was performed at the base of the PM due to the presence of polymorphic ventricular arrhythmias, using the CARTO 3 System to guide the ablation (Figure 2). Both PM electrical isolations were successful and the patients did not repeat the clinical arrhythmia during follow-up. Ablation-associated mortality was 0% and major complications were 2.5% (non-surgical cardiac tamponade in one patient). No minor complications were recorded. Median follow-up was 282 days (IQR 152-549).

A)	RF (n=22)	Cryo (n=18)	p value
Age, years	49±16.2	42±15.8	0.57
Male gender, n	19	9	0.047
HTN, n	6	1	0.094
DBT, n	2	2	0.761
SCM, n	8	3	0.207
LVEF, %	51.2±12.9%	59.5±5.2	> 0.0001
LVDD, mm	56±8.35	51.4±5.92	0.149
LVSD, mm	40.8±10.8	33.1±6.02	0.04
MR, n	8	5	0.699
MVP, n	3	5	0.212
NSVT, n	7	10	0.075
VES, n	13	3	0.05
VT, n	4	5	0.075

B)	PMPM (n=37)			ALPM (n=5)		
	Apex (n=4)	Apex (n=4)	Apex (n=4)	Apex (n=4)	Apex (n=4)	Apex (n=4)
QRS	Rr	Rsr	rSR/Rsr	Rr	Rsr	rSR/Rsr
Axis	S	S	S	I	I	I
R/S	V6	V5	V4/V3	V6	V4/V5	V4/V5
Lead I	ISO	ISO	POS/ISO	NEG	NEG	NEG

RF: Radiofrequency ablation. Cryo: Cryoenergy ablation. N: number of patients. HTN: Hypertension. DBT: Diabetes. SCM: Structural cardiomyopathy. EF: Left ventricular ejection fraction. LVDD: Left ventricular diastolic diameter. LVSD: Left ventricular systolic diameter. MR: Mitral valve regurgitation. MVP: Mitral valve prolapse. NSVT: Non-sustained ventricular tachycardia. VES: Ventricular extrasystoles. VT: Ventricular tachycardia. PMPM: Posteromedial papillary muscle. ALPM: Anterolateral papillary muscle. QRS: QRS complex. Axis: QRS electrical axis. S: Superior. I: Inferior. R/S: Precordial lead where the transition between a predominantly positive to a predominantly negative QRS complex is produced. Lead I: Frontal left-right lead. ISO: Isodiphasic QRS complex. POS: Predominantly positive QRS complex. NEG: Predominantly negative QRS complex.

Table 1. Clinical (A) and electrocardiographic (B) characteristics of the population.

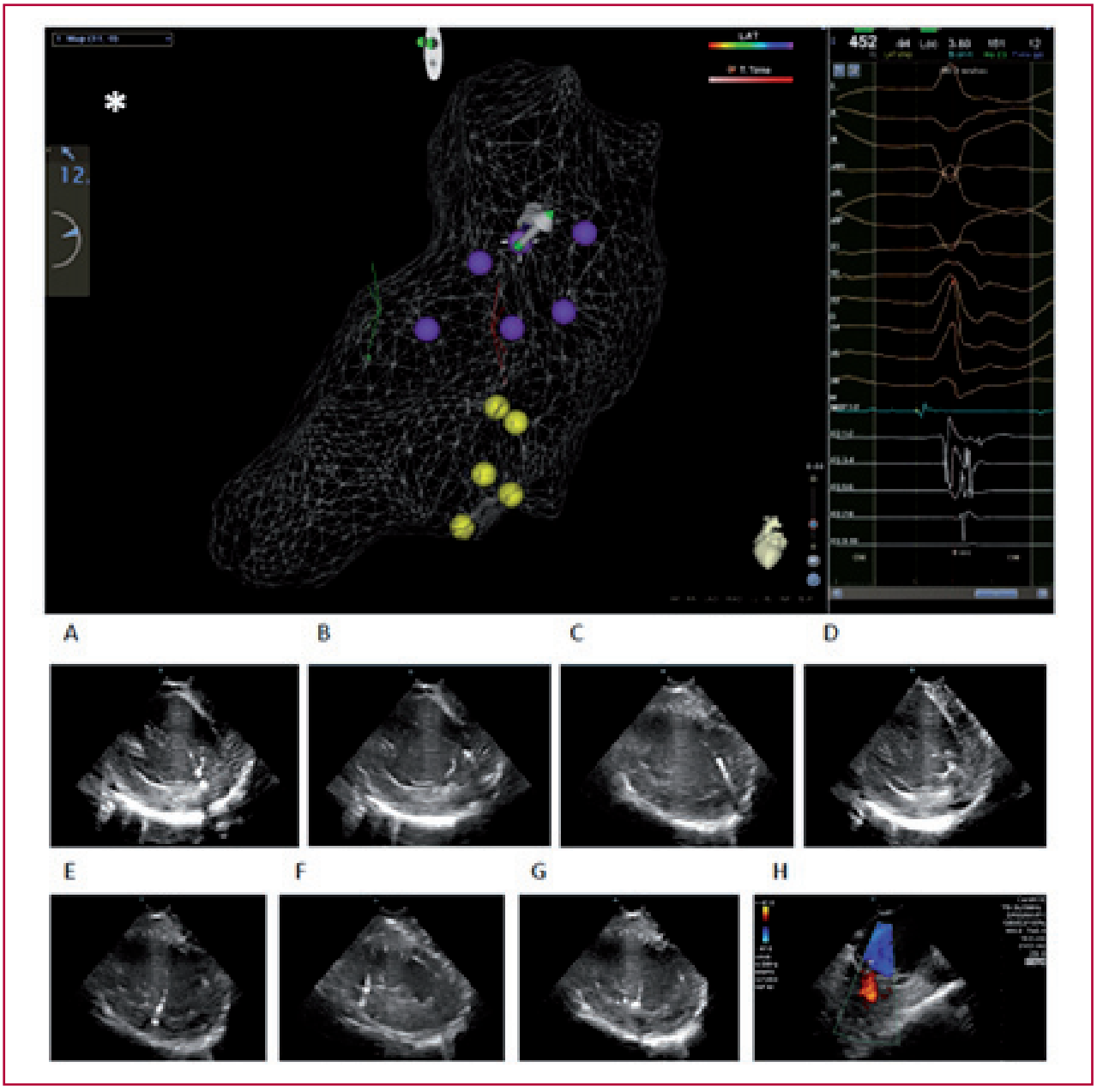

Fig. 2. * Circumferential isolation of left ventricular papillary muscles. The figure shows the left ventricular anatomical map. Color points correspond to the limits of both papillary muscle bases (purple: anterolateral and; yellow: posteromedial papillary muscle base), demarcated using a 3.5 mm open-irrigated ablation catheter and contact sensor (SmartTouch SF, BiosenseWebster Inc). A focal, 8 mm cryoablation catheter was used to apply cryoenergy in each of these points to achieve electrical isolation of the papillary muscles (loss of ventricular capture during continuous stimulation from the PM).
Below: Intracardiac echocardiography during circumferential isolation of left ventricular papillary muscles. **A)** Eight mm cryoablation catheter situated on the base of the anterolateral papillary muscle, at the level of the inferior aspect; **B)** superior aspect; **C)** anterior aspect (notice the catheter positioned in front of the papillary muscle; **D)** posterior aspect.
Focal cryoablation catheter situated on the base of the posteromedial papillary muscle at the **E)** anterior; **F)** posterior and **G)** septal level; **H)** Mitral valve monitoring after cryoablation. Notice absence of mitral valve regurgitation by color Doppler.

Cryoenergy vs radiofrequency

Table 1 shows the general characteristics of patients treated with CRY or RF ablation. The primary success rate was 83% for RF and 100% for CRY. Mortality was 0% in both cases and only one major complication was encountered (cardiac tamponade) in the RF group. As shown in Table 2, the effective lesion (VEGM-QRS interval and PM score) criteria and success markers were similar in both groups.

The rate of recurrence in the RF ablation group was significantly higher than in the CRY group (46% vs. 3.7%, p=0.01) during an average follow-up of 329.5

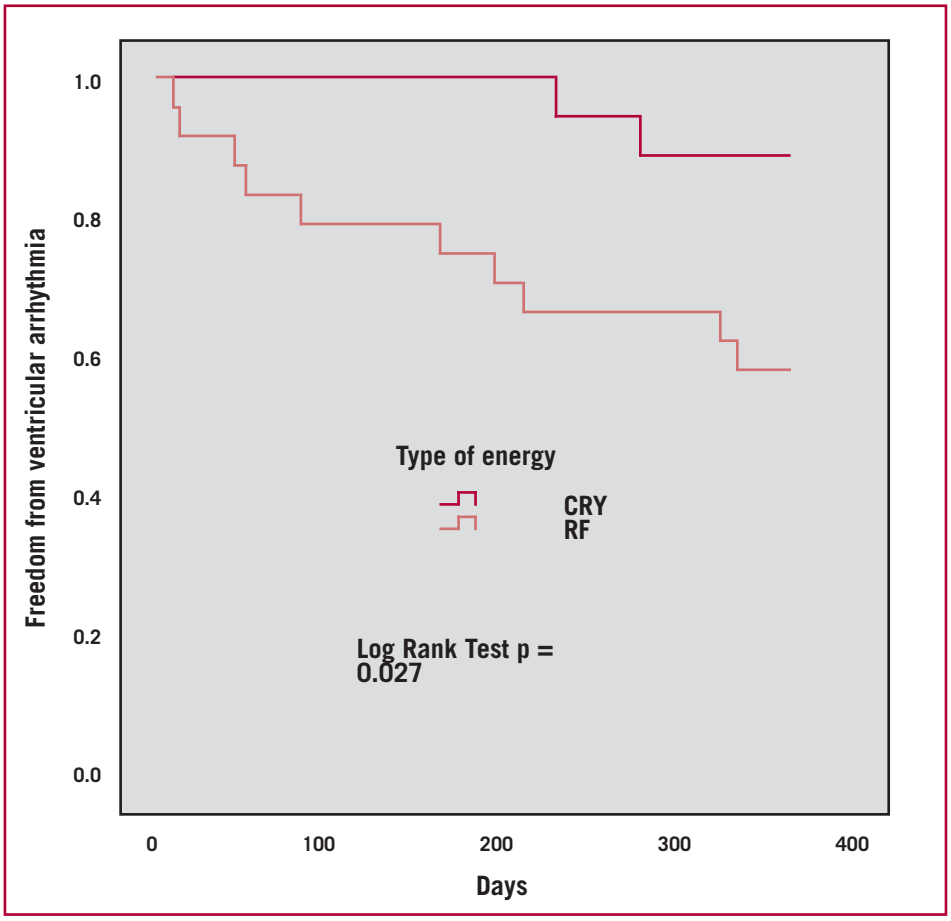

Fig. 3. Kaplan-Meier curves showing freedom from clinical arrhythmia after catheter ablation. CRY: Cryoenergy; RF : Radiofrequency.

days (IQR 110-366) for RF vs 282.5 days (IQR 160-706) for CRY (Figure 3).

Predictors of recurrence

Table 2 depicts the predictive variables of PM-originated VA recurrence at one year, using Cox regression analysis. Of interest, RF increased by 20% the risk of post-ablation VA recurrence.

DISCUSSION

Almost 20% of patients included in the study presented MVP, two of them with severe regurgitation in both leaflets. Thirty percent of the population had mild mitral valve regurgitation in most cases. Catheter ablation primary success rate was high, and patients treated with cyoablation had a significantly lower rate of recurrence. This study also included the first two cases reported in the literatures of PM circumferential isolation for the treatment of polymorphic ventricular arrhythmias.

Anatomically, left ventricular PM are structures of considerable thickness, with conic projections to the ventricular wall and irregularly distributed myocardial bands. (10) In addition, myocardial fibers are intermingled with Purkinje fibers, creating a substrate for the development of ventricular arrhythmias. (11) These arrhythmias present particular electrophysiological characteristics. (12) The arrhythmogenic mechanism of PM VT was initially described as focal. (13, 14) However, there is frequently presence of multiple spontaneous or ablation-triggered morphologies, (15) which can be attributed to a differential conduction towards multiple exit sites induced by muscle anisotropy or generated according to the source of energy used. (16) The identification of Purkinje potentials at the site of arrhythmia origin is controversial. (12-14, 16) and in our study they were observed in 65% of cases, mainly at the base of PM, suggesting that the Purkinje network would not extend beyond the body of these muscles. (16, 17) The most arrhythmogenic substrate is the PMPM, (16) which is the most frequent site of origin of PM-related arrhythmias, and may act as triggers of polymorphic VT and ventricular fibrillation. (4, 5) In this study we observed that the electrocardiographic characteristics of arrhythmias originating in the PM mainly include right bundle branch block morphology with Rsr' or rSR' patterns in lead V1. The electrical axis determines the implicated PM. Arrhythmias with superior electrical axis correspond to the PMPM, whereas those with inferior axis are originated in the anterolateral papillary muscle (ALPM). Transition from R to S (R/S) in precordial leads is a characteristic feature of this type of arrhythmias. They allow their differentiation

Table 2. Procedure characteristics (A) y predictors of recurrence (B).

A)	RF	Cryo	p value
Primary success, n	20	18	0.06
Complications, n	1	0	0.4
Mortality, n	0	0	-
Recurrence, n	11	2	0.02
ICE, n	9	18	> 0.0001
Follow-up, median days	329.5(110-366)	282.5(160-706)	0.5
Fluoroscopy time, min	14.37±4.58	10.83±4.46	0.5
Procedure time, min	144±46	133±26	0.009
Energy dose, s	364±178	753±328	0.003
VEGM-QRS, ms	34 (30-36)	33,5 (29,7-37,2)	0.8
PMAS , median score	22	22	0.7
Stability, %	30	100	0.02
B)	**Hazard Ratio**		**p value**
Sex	1.024 (0.308 - 3.404)		NS
Age	1.007 (0.972 - 1.043)		NS
LVEF	0.978 (0.935 - 1.023)		NS
HTN	1.021 (0.224 - 4.661)		NS
DBT	0.930 (0.120 - 7.209)		NS
SCM	1.242 (0.363 - 4.244)		NS
Pro A	2.897 (0.871 - 9.633)		NS
Stability	0.317(0.095 - 1.053)		NS
RF	0.212 (0.046 - 0.968)		0.04
No ICE	0.113 (0.030 - 0.420)		0.001

RF: Radiofrequency ablation. Cryo: Cryoenergy ablation. n: Number of patients. ICE: Intracardiac echocardiography. VEGM-QRS: Interval between the earliest ventricular activation recorded by the mapping electrode and the onset of the QRS complex (predictor of ablation success when it is >20ms). PMAS: Papillary muscle arrhythmia score obtained from the correlation between the QRS complex of the clinical arrhythmia and the QRS complex achieved by ventricular stimulation at the level of arrhythmia origin. Stability: When the ablation catheter remained fixed in the effective ablation site during energy delivery. LVEF: Left ventricular ejection fraction. HTN: Hypertension. DBT: Diabetes. SCM: Structural cardiomyopathy. Pro A: Pro-arrhythmia during energy delivery. Stability: Catheter stability during ablation. RF: Radiofrequency. No ICE: Ablation performed without intracardiac echocardiography.

from arrhythmias originated in the mitral annulus, which are usually consistent in all precordial leads, suggesting a basal origin. The presence of positive complexes in lead I and aVL indicate a PMPM origin, while predominantly negative complexes point to an ALPM cause. (18) Thus, the electrical axis and Lead I and aVL leads are useful to differentiate the culprit PM. The inferior electrical axis and negative complex in lead I and aVL suggest a ALPM origin, whereas a superior electrical axis and positive complex in lead I and aVL a PMPM origin. Moreover, the ascending branch of the QRS presents great amplitude and fast onset, implying a certain degree of fusion with Purkinje fibers. QRS duration allows differentiating this type of arrhythmias from those exclusively originated in the left branch fascicles, with QRS ≤135 ms and mainly a rsR' pattern (r<R'). (12-14) Fascicular arrhythmias also exhibit a typical Q wave in lead I or aVL, while those arising in PMPM present a typical R or Rs pattern. (18) Recently, a new group of fascicular arrhythmias was described, that may originate in the Purkinje network around the left ventricular PM. (19) In these cases, the ECG would exhibit shared characteristics because histologically, the PM reveal a network of muscle fibers and Purkinje fibers, enabling their variable recruitment (19-21). This fiber arrangement would explain, though not frequently, the presence of r<R patterns in this study.

Some studies report lack of correlation between the stimulation map and the site of early arrhythmia activation, with discordances between sites with elevated electrocardiographic correlation and premature activation sites. (22) For this reason, ablation success essentially depends on stimulation mapping. Some theories explaining this phenomenon include multiple exit sites, a distant arrhythmogenic substrate with a possible common exit site, adjacent myocardium capture, and capture of the fascicle corresponding to the left branch of the conduction system with varying impulse amplitude. In many cases, the presence of a premature, low amplitude potential (distant field signal) at the effective activation site would suggest an intramyocardial origin. (23)

Radiofrequency catheter ablation often requires high doses of energy, even at both sides of the muscles, (24) and the rate of recurrence may reach 58% of cas-

es. (1-3, 23) Adequate stability with the ablation catheter in the electrode-myocardium interface is a great challenge. The brushing effect of the muscle may even generate multiple types of arrhythmia, increasing the complexity of the procedure. (16, 17) Complications, such as intramyocardial vapor bubbles, exclusively associated to the use of RF with open-irrigated ablation catheters, increase the risk of complications as PM dysfunction or rupture, a finding still not reported in the literature.

These difficulties led us to implement new ablation strategies, including the use of alternative energy sources as CRY. Our initial experience demonstrated initial encouraging results, both in primary success as in recurrence rates. (17) The biophysical CRY profile allows keeping an undamaged histological architecture of the tissue, without generating endothelial disruption or superficial thrombus. No intramyocardial vapor accumulation is observed with this technique. One of its main advantages resides in the ability of the ablation catheter to attach to the myocardium, conferring stability during energy delivery. In cases where this energy source was used, stability was 100%, with no increase in the incidence of polymorphic arrhythmias, (16, 17) attributed to the absence of the brushing effect observed with RF catheters.

In cases where arrhythmias with multiple morphologies are observed, electrical circumferential isolation of the PM base is an acceptable therapeutic alternative. (25, 26)

The vast majority of MVPs course as a benign disease. However, a reduced group of patients, mainly women with prolapse of both leaflets, complex ventricular arrhythmia and electrocardiographic alterations of T waves, conform a syndrome recently described as malignant MVP. (27) An incidence of sudden death of up to 40% has been described for this group and 100% of cases present fascicular and PM arrhythmias. (27) Catheter ablation of these foci showed a high success rate (89%), with need of repeating the procedure in 42% of cases and with symptom and appropriate defibrillator discharge reduction. (27)

Importance of image integration

For different reasons, ICE image integration represents the cornerstone of this type of procedure: (16, 17) It allows, direct, real-time visualization of chamber structures, facilitating the navigation of the ablation catheter; it provides continuous monitoring of catheter contact in the electrode-myocardium interface during stimulation mapping, activation and energy delivery; it allows the development of activation maps limited to the corresponding PM; and it facilitates the demarcation of ablation points on both sides of the PM. In previous studies, we have shown how 3D electro-anatomical mapping systems assisted by ICE (CARTOSOUND, Biosense-Webster, Inc. Diamond Bar, CA) also represent an extremely useful tool. (28)

Limitations

The number of patients included in the study was limited, mainly because this is a scarcely prevalent arrhythmia. Moreover, the study was not randomized to compare different energy sources for the ablation of PM arrhythmias. Patients treated with CRY had higher use of ICE than those undergoing RF ablation; however, ICE does not correspond to a direct treatment method and the predicted ablation success variables (stimulation maps, VEGM-QRS interval) were similar in both groups. No catheters with pressure sensors (Contact Force) were used for the ablation or ICE-integrated 3D mapping systems, which might have conditioned the results.

CONCLUSIONS

Arrhythmias originating in the left ventricular PM were associated with MVP in almost 20% of cases. The R>r' pattern in V1 lead, QRS duration >135 ms and presence of R/S transition in precordial leads were the most frequent electrocardiographic features. The electrical axis and the presence of positive or negative complexes in lead I and aVL are useful to detect the involved PM. Catheter ablation is an effective and safe procedure. Use of CRY and ICE is associated with a lower recurrence of the clinical arrhythmia.

Acknowledgement

To Laura Gutiérrez and Nicolás Berney of Instituto Cardiovascular de Buenos Aires, Buenos Aires, Argentina.

Conflicts of interest

None declared
(See author´s conflicts of interest forms on the web / Supplementary Material)

REFERENCES

1. Good E, Desjardins B, Jongnarangsin K, Oral H, Chugh A, Ebinger M, et al. Ventricular arrhythmias originating from a papillary muscle in patients without prior infarction: A comparison with fascicular arrhythmias. Heart Rhythm 2008;5:1530-7. http://doi.org/dnqj6c

2. Yamada T, Doppalapudi H, McElderry T, Okada T, Murakami Y, Inden Y, et al. Electrocardiographic and electrophysiological characteristics in idiopathic ventricular arrhythmias originating from the papillary muscles in left the left ventricle: Relevance for catheter ablation. Circ Arrhythm Electrophysiol 2010;3:324-31. http://doi.org/b2ft4r

3. Nogami A, Naito S, Tada H, Oshima S, Taniguchi K, Aonuma K, et al. Verapamil-sensitive left anterior fascicular ventricular tachycardia: Results of radiofrequency ablation in six patients. J Cardiovasc Electrophysiol 1998;9:1269-78. http://doi.org/c4cptx

4. Van Herendael H, Zado ES, Haqqani H, Tschabrunn CM, Callans DJ, Frankel DS, et al. Catheter ablation of ventricular fibrillation: importance of left ventricular outflow tract and papillary muscle triggers. Heart Rhythm 2014;11:566-73. http://doi.org/f5v5w6

5. Santoro F, Di Biase L, Hranitzky P, Sanchez JE, Santangeli P, Perini AP, et al. Ventricular fibrillation triggered by PVCs from papillary muscles: clinical features and ablation. J Cardiovasc Electrophysiol 2014;25:1158-64. http://doi.org/cjbk

6. Santoro F, Di Biase L, Hranitzky P, Sánchez JE, Santangeli P, Perini AP, et al. Ventricular tachycardia originating from the septal papillary muscle of the right ventricle: electrocardiographic and electrophysiological characteristics. J Cardiovasc Electrophysiol 2015;26:145-50. http://doi.org/cjbm
7. Crawford T, Mueller G, Good E, Jongnarangsin K, Chugh A, Pelosi F Jr, et al. Ventricular arrhythmias originating from the papillary muscles in the right ventricle. Heart Rhythm 2010;7:725-30. http://doi.org/bpdvcr
8. Syed FF, Ackerman MJ, McLeod CJ, Kapa S, Mulpuru SK, Sriram CS, et al. Sites of Successful Ventricular Fibrillation Ablation in Bileaflet Mitral Valve Prolapse Syndrome. Circ Arrhythm Electrophysiol 2016;9:e004005. http://doi.org/cjbn
9. Coggins DL, Lee RJ, Sweeney J, Chein WW, Van Hare G, Epstein L, et al. Radiofrequency catheter ablation as a cure for idiopathic tachycardia of both left and right ventricular origin. J Am Coll Cardiol 1994;23:1333–41. http://doi.org/bg7f47
10. Madhavan M, Asirvatham SJ. The fourth dimension: endocavitary ventricular tachycardia. Circ Arrhythm Electrophysiol 2010;3:302-4. http://doi.org/c7t57c
11. Naksuk N, Kapa S, Asirvatham SJ. Spectrum of Ventricular Arrhythmias Arising from Papillary Muscle in the Structurally Normal Heart. Card Electrophysiol Clin 2016;8:555-65. http://doi.org/cjbp
12. Kawamura M, Hsu JC, Vedantham V, Marcus GM, Hsia HH, Gerstenfeld EP, et al. Clinical and electrocardiographic characteristics of idiopathic ventricular arrhythmias with right bundle branch block and superior axis: Comparison of apical crux area and posterior septal left ventricle. Heart Rhythm 2015;12:1137-44. http://doi.org/f7ckz9
13. Nogami A. Purkinje-related arrhythmias part II: polymorphic ventricular tachycardia and ventricular fibrillation. Pacing Clin Electrophysiol 2011;34:1034–49. http://doi.org/fjq378
14. Nogami A. Purkinje-related arrhythmias part I: monomorphic ventricular tachycardias. Pacing Clin Electrophysiol 2011;34:624–50. http://doi.org/b8k37p
15. Al'Aref SJ, Ip JE, Markowitz SM, Liu CF, Thomas G, Frenkel D, et al. Differentiation of Papillary Muscle From Fascicular and Mitral Annular Ventricular Arrhythmias in Patients With and Without Structural Heart Disease. Circ Arrhythm Electrophysiol 2015;8:616-24. http://doi.org/f7hfbf
16. Rivera S, Ricapito MP, Tomas L, Parodi J, Bardera Molina G, et al. Results of cryoenergy and radiofrequency-based catheter ablation for treating ventricular arrhythmias arising From the papillary muscles of the left ventricle, guided by intracardiac echocardiography and image integration. Circ Arrhythm Electrophysiol 2016;9:e003874. http://doi.org/cjbq
17. Rivera S, Ricapito MP, Espinoza J, Belardi D, Albina G, Giniger A, et al. Cryoablation for ventricular arrhythmias arising from the papillary muscles of the left ventricle guided by intracardiac echocardiography and image integration. J Am Coll Cardiol EP 2015;1:509-16. http://doi.org/cjbr
18. Deyell MW, Man JP, Supple GE, Hutchinson MD, Frankel DS, Marchlinski FE. ECG Differentiation Of Ventricular Arrhythmias Arising From The Left Posterior Fascicle And Postero-medial Papillary Muscle. Heart Rhythm 2012;9:S474.
19. Komatsu Y, Nogami A, Kurosaki K, Morishima I, Masuda K, Ozawa T, et al. Circ Arrhythm Electrophysiol 2017;10:e004549. http://doi.org/cjbs
20. Nogami A. Purkinje-related arrhythmias part II: polymorphic ventricular tachycardia and ventricular fibrillation. Pacing Clin Electrophysiol 2011;34:1034–49. http://doi.org/fjq378
21. Nogami A. Purkinje-related arrhythmias part I: monomorphic ventricular tachycardias. Pacing Clin Electrophysiol 2011;34:624–50. http://doi.org/b8k37p
22. Doppalapudi H, Yamada T, McElderry T, Plumb VJ, Epstein A, Kay N. Ventricular tachycardia originating from the posterior papillary muscle in the left ventricle. A distinct clinical syndrome. Circ Arryhthm Electrophysiol 2008;1:23-9. http://doi.org/c4zktf
23. Yamada T, McElderry T, Doppalapudi H, Kay N. Ventricular far-field activity may provide a diagnostic challenge in identifying an origin of ventricular tachycardia arising from the left ventricular papillary muscle. Europace 2009;11:1403-5. http://doi.org/c4zktf
24. Latchamsetty R, Yokokawa M, Morady F, Kim HM, Mathew S, Tilzet R, et al. Multicenter outcomes for catheter ablation of idiopathic premature ventricular complexes. J Am Coll Cardiol EP 2015;1:116–23. http://doi.org/dv7gtm
25. Liu XK, Barrett R, Packer D, Asirvatham SJ. Successful management of recurrent ventricular tachycardia by electrical isolation of anterolateral papillary muscle. Heart Rhythm 2008;5:479-82. http://doi.org/cjbv
26. Wo HT, Liao FC, Chang PC, Chou CC, Wen MS, Wang CC, et al. Circumferential ablation at the base of the left ventricular papillary muscles: A highly effective approach for ventricular arrhythmias originating from the papillary muscles. Int J Cardiol 2016;220:876-82. http://doi.org/cjp55r
27. Syed FF, Ackerman MJ, McLeod CJ, Kapa S, Mulpuru SK, Sriram CS, et al. Sites of Successful Ventricular Fibrillation Ablation in Bileaflet Mitral Valve Prolapse Syndrome.Circ Arrhythm Electrophysiol 2016;9:e004005. http://doi.org/f83dq4
28. Proietti R, Rivera S, Dussault C, Essebag V, Bernier ML, Ayala-Paredes F, et al. Intracardiac echo-facilitated 3D electroanatomical mapping of ventricular arrhythmias from the papillary muscles: assessing the 'fourth dimension' during ablation. Europace 2016;19:21-8. http://doi.org/cjbn