Title page

The title: Multipolar mapping for catheter ablation of premature ventricular complexes originating from papillary muscles in the structurally normal heart

The names of the authors: Chi Cai, MD, PhD, Jing Wang, MD, PhD, Hongxia Niu, MD, PhD, Wei Hua, MD, PhD, Jianmin Chu, MD, PhD and Shu Zhang, MD, PhD.

The institutions of all authors: The Cardiac Arrhythmia Center, State Key Laboratory of Cardiovascular Disease, Fuwai Hospital, National Center for Cardiovascular Diseases, Chinese Academy of Medical Sciences and Peking Union Medical College

Acknowledgements: None.

Disclosures: Conflicts of interest: None.

The corresponding author: Name: Jing Wang; Tel: +86 10 88396963; Email: doctorjingwang@126.com; Mailing address: The Cardiac Arrhythmia Center, Fuwai Hospital, Beilishi road No. 167, Xicheng district, Beijing, China; Postal code: 100037.

Introduction: Previous studies on radiofrequency catheter ablation of premature ventricular complexes (PVCs) arising from the left ventricle (LV) papillary muscles (PM) show a modest procedural success rate with higher recurrence rate. This study explored the utility of using a multipolar catheter for ablating the PM PVCs.

Methods and Results: Endocardial mapping was performed via retrograde aortic approach using a steerable duodecapolar catheter in 6 patients and conventional point-by-point catheter in 5 patients, respectively. Compared with patients in point-by-point catheter group, duodecapolar catheter mapping demonstrated higher efficiency with an average procedure time and fluoroscopy time. The values of earliest activation time during mapping using duodecapolar catheter were significantly greater (32.3 ± 3.9 ms vs. 25.4 ± 2.8 ms). The mean number of ablation applications points in the duodecapolar catheter group was 6.8 ± 1.9 with an average overall ablation duration of 6.1 ± 3.0 minutes, which was significantly less compared to the point-by-point catheter group. There were no complications in duodecapolar catheter group whereas one cardiac tamponade occurred in the point-by-point catheter group. All 6 patients (100%) in the duodecapolar catheter group demonstrated acute successful ablation whereas only 3 of the 5 patients (60%) with point-by-point catheter ablation succeeded, and the intermediate success rate remained the same after an average follow-up of 9.7 ± 3.2 months.

Conclusions: Mapping and ablation of PM PVCs using a duodecapolar catheter facilitated identification of earliest activation potentials and pace mapping, and

demonstrated a high success rate during follow-up when compared to conventional mapping techniques.

Key words： Papillary muscles; Premature ventricular complexes; Duodecapolar catheter mapping; Catheter ablation

Introduction

Papillary muscles (PM) of the left ventricle (LV) are a source of premature ventricular complexes (PVCs) in patients with or without structural heart disease.[1, 2] Given their anatomic complexity and independent motion during the cardiac cycle, radiofrequency catheter ablation of PVCs arising from the PM has a fair procedural success rate and higher recurrence rate compared with other locations.[3] Because of the anatomical variability and the relative instability of the ablation catheter at these sites, successful point-by-point mapping to identify the ablation targets can be time-consuming and operator dependent. Recent studies have shown that ultra high-density mapping with multipolar catheters has been shown to be accurate and expeditious in the mapping of complex reentrant atrial arrhythmias and scar-mediated ventricular tachycardias.[4, 5] Multipolar mapping may hold promise for facilitating an accurate and more efficient identification of ectopic foci in PM regions, thereby improving procedural success rates for PM PVC ablation. Nevertheless, currently published studies regarding PM PVC ablation using ultra high-density mapping approaches are still limited. The aim of this study is to present our experience with a multipolar mapping technique using a duodecapolar (20-electrodes) catheter (St. Jude Medical, St. Paul, MN, USA) for mapping and ablation of PM PVCs in a case series of patients with structurally normal hearts, and we sought to compare clinical features and procedural data as well as success rates after catheter ablation between the duodecapolar mapping technique and a conventional point-by-point mapping technique.

Methods

Study Population

This study investigated 11 consecutive patients with PVCs arising from the LV PM in whom ablation was performed using a retrograde aortic approach at Fuwai hospital between November 2018 and December 2019. All subjects met the following inclusion criteria: frequent symptomatic PVCs despite antiarrhythmic treatment and no presence of underlying cardiomyopathy based on preprocedural echocardiography. Antiarrhythmic agents were discontinued for at least 5 half-lives before the procedure. All patients signed informed consent forms, and the study complied with the Declaration of Helsinki and was approved by the Research Ethics Board of Fuwai Hospital.

Data collection

Data including demographics, echocardiographic parameters, 24-hour Holter monitoring, laboratory values, and medications at the initial evaluation were retrospectively obtained from the electronic medical record. Echocardiography and 24-hour Holter monitoring were prospectively performed before discharge and at 3, 6, and 12 months during follow-up in all patients through chart review or a telephone interview. Arrhythmia recurrence was assessed by 12-lead electrocardiograms (ECG) and 24-hour Holter monitoring recordings.

Echocardiographic evaluation

Transthoracic echocardiograms were obtained before and within 24 hours following the ablation procedure as well as during final follow-up for all patients. Echocardiographic

parameters including the left atrium diameter (LAD) and left ventricular end-diastolic diameter (LVEDD) were measured using a commercially available system (iE33; Philips Medical Systems) equipped with a 3.5-MHz transducer according with the recommendations of the American Society of Echocardiography protocols.[6] The left ventricular ejection fraction (LVEF) was calculated using the modified biplane Simpson's rule from apical imaging planes. The severity of mitral regurgitation (MR) was assessed semi-quantitatively according to regurgitant area and orifice width using the color-flow Doppler images at the parasternal long-axis.

Mapping and ablation procedure

The procedures were performed under local anesthesia without sedation. Local right groin anesthesia was performed with xylocaine 1%, 5–10 ml. A 3-dimensional electroanatomic mapping system (Ensite NavX velocity system, St Jude Medical) was used in all patients. Under fluoroscopy, the decapolar catheter with 5-mm electrodes and 2-mm interelectrode spacing was placed in the coronary sinus (CS) by the right internal jugular vein route, with the proximal poles located at the CS ostium. Right femoral artery access was subsequently established with an 8F sheath and anticoagulation with heparin was initiated to maintain a target activated clotting time of 250–350 seconds. Surface 12-lead ECG and intracardiac electrograms were recorded continuously with a speed of 100 mm/sec on LabSystem Pro (Bard Electrophysiology, Lowell, MA).

LV endocardial electroanatomic mapping was performed via the right femoral artery and longitudinally retrograde approach using either a steerable linear duodecapolar

catheter (5F, 1-mm tip and 2-2-2 mm spacing electrodes, Livewire, St. Jude Medical, St. Paul, MN, USA) or an open irrigated deflectable quadrupolar 3.5-mm-tip FlexAbility ablation catheter (St. Jude Medical, St. Paul, MN, USA) for point-by-point mapping during sinus rhythm with spontaneous PVCs. Following the completion of activation mapping, and once all earliest prepotential bipolar activity observed on the mapping catheter was tagged, pace mapping was performed at these sites for comparison with the clinical PVC 12-lead ECG template. Perfect pace map match was defined as a 12/12 lead match and good pace map match was defined as a 10/12 match.

Ablation applications were typically performed at the myocardial sites exhibiting the earliest bipolar activity with a local unipolar QS pattern with a local activation preceding the QRS onset by ≥25 milliseconds during PVCs combined with perfect/good pace maps, which were tagged on the electroanatomic map. Upon mapping completion, the duodecapolar catheter was replaced by an ablation catheter, through the retrograde approach with an open irrigated deflectable quadripolar 3.5-mm-tip FlexAbility and ablation performed at 30-40W, temperature limit 45℃ @ 17 mL flow rate.[7]. The RF output was adjusted according to impedance drop and temperature at the operator's discretion. The following parameters were recorded for each ablation application: average RF output, average impedance drop and duration of ablation. If the RF application elicited a suppression or elimination of the PVCs within the initial 30 seconds, the application was maintained for ≤120 seconds, targeting an impedance drop of 10 - 15 Ω or a diminution or abolishment of the local electrogram. After the ablation

procedure, intravenous isoproterenol (2-10 μg/min) and burst pacing from the RV was performed to assess arrhythmia inducibility. Acute procedural success was defined as abolition of either inducible or spontaneous clinical PVCs at the end of the ablation procedure. The intermediate success rate of catheter ablation was defined as a significant reduction (reduction of the clinical PVC burden by ≥85%) at 3, 6, and 12 months follow-up; otherwise, the outcome was considered as clinical arrhythmia recurrence.

Statistics

Continuous data are presented as mean ± SD, and dichotomous data are expressed as numbers and percentages. Continuous data were compared using unpaired Student *t* tests and Mann-Whitney *U* tests for normally and non-normally distributed variables, respectively. The χ^2 tests or Fisher's exact tests were used to compare dichotomous data. All analyses were performed with SPSS for Windows, version 19.0 (SPSS, Chicago, USA). A two-sided p value <0.05 was considered statistically significant.

Results

Baseline characteristics

A total of 11 consecutive patients were included in this study. The demographics and clinical characteristics of this study population at baseline are summarized in Table 1. Of those, 5 (45.5%) were male. The average age was 41±18 years and the average BMI was 22.6 ± 2.2 kg/m^2. The whole study cohort had normal cardiac structure and function with a mean LVEDD of 46.6 ± 4.8mm and LVEF of 63.0 ± 3.4%. All patients

displayed a high PVC burden (mean 18.6% ± 8.2%) and 7 (63.6%) presented with non-sustained ventricular tachycardia (NSVT). All the patients received medical therapy before ablation, with β -blockers used in 54.5% of patients.

Patients were then further divided into two groups according to whether a duodecapolar catheter was used for mapping. Compared with patients in the point-by-point catheter group, patients with duodecapolar catheter mapping were significantly younger (31 ± 13 vs. 53 ± 16 years, p=0.033). Moreover, the burden of PVCs (21.4% ± 10.7% vs. 16.2% ± 5.4%) and NSVT (83.3% vs. 40.0%) tended to be much higher in the duodecapolar catheter group. There were no significant differences in the clinical characteristics including sex, BMI and duration of symptoms as well as echocardiographic, laboratory tests, comorbidities and medication characteristics between these two groups.

Procedure and ablation characteristics

The procedural characteristics and ablation data for the two groups of patients are shown in Table 2. The ablation procedure was the first attempt in all patients. Compared to patients mapped with a point-by-point catheter technique, patients in the duodecapolar catheter group had a shorter mean procedure time and fluoroscopy time ($p<0.001$ and $p=0.002$, respectively) and had significantly shorter overall ablation duration as well as fewer ablation applications ($p=0.006$ and $p=0.001$, respectively). Additionally, the values of earliest activation time relative to QRS onset during mapping were also significantly earlier in the duodecapolar catheter group (32.3 ± 3.9ms vs. 25.4

± 2.8ms, p=0.008). Perfect/good pacemaps were seen in all patients (100%) with the duodecapolar catheter, higher compared to patients using a point-by-point catheter (60%). In contrast, non-significant differences were noted in the average ablation output and impedance drop between the two groups. There were no complications in duodecapolar catheter group whereas one non-surgical cardiac tamponade related to the ablation occurred in the point-by-point catheter group. Overall acute success rate was 81.8%. Patients treated using the duodecapolar catheter showed 100% acute success rate, while those treated using point-by-point catheter demonstrated a 60% acute success rate (p=0.182) and reappearance occurred with an identical morphology in the remaining two patients following the ablation procedure.

As mentioned, a detailed LV activation and pace map was performed in 6 patients via a retrograde aortic approach using a duodecapolar mapping catheter (Figure 1 and 2). A total of 12 different PM PVC were mapped in the 11 patients. The sites of PVC origin included the anterior papillary muscles (APM) in 5 (45.5%), the posterior papillary muscles (PPM) in 5 (45.5%) patients and both PMs in 1 (9%) patient. The APM PVCs accounted for 80.0% (4 patients) of the point-by-point mapping group, which was more commonly seen than in the duodecapolar mapping group (33.3%, 2 patients).

Follow-up

After a follow-up period of 9.7 ± 3.2 months, the PVC burden in all patients decreased from 31% to 3%, with reduction from 21.4 % to 1% in the duodecapolar group and 16.2% to 5% in the point by point group respectively. The patients in the duodecapolar group

were not taking any medication while two patients in the point by point group were managed with mexiletine after recurrence of PVCs and mild symptoms. Thus, the intermediate success rate remained the same as the acute success rate before hospital discharge in these two groups (100% vs. 60%, respectively). During reevaluation by echocardiography, no exacerbation of mitral regurgitation, an no aortic valve, cardiac structural or functional changes occurred using either method. No complications were observed at the end of follow-up.

Discussion

Idiopathic PVCs from the PM may present both in patients with and without structural heart disease and may play a role in triggers of NSVT, sustained recurrent VT, or even ventricular fibrillation (VF).[8, 9] Mapping and catheter ablation of clinical PM PVCs are challenging because of the complexity of PM anatomy and their constant motion during the cardiac cycle.[10] In this study, we performed detailed activation mapping using a duodecapolar mapping catheter in order to achieve faster and more precise delineation of the site of origin of arrhythmia, and the efficacy of this novel technique was compared to conventional mapping technique in a relatively small PM PVC cohort. The most important finding of the present study is that the use of a duodecapolar catheter is feasible and highly efficient for finding the sites of earliest prepotential bipolar activity and good/perfect pace maps, leading to successful elimination of PM PVCs.

As is known, high-density mapping with multipolar catheters is a technique with proven value for activation mapping and electroanatomic substrate delineation in

macroreentrant atrial tachycardia, atrial fibrillation as well as ventricular tachycardia.[4, 11-13] In the current study, to our knowledge, we are the first to describe a technique using a duodecapolar catheter for endocardial electroanatomic mapping and as a guide for ablation of PM PVCs. Significantly earlier activation potentials were identified during mapping with the duodecapolar mapping catheter in this study. With 2-mm interelectrode spacing, good or perfect pace maps can be generated within a given small area after ultra high-density activation mapping with a multipolar catheter. The present results have demonstrated that patients with duodecapolar catheter mapping had shorter procedure and fluoroscopy times and had significantly shorter ablation duration as well as fewer ablation applications when compared to patients with conventional point-by-point catheter mapping. Furthermore, the rate of complete PM PVC elimination tended to be higher when using multipolar catheters.

Notably, ablation of PM PVCs has a variable success rate because of challenges in mapping and catheter stability. The outcomes of catheter ablation in our series were reasonably good. Acute procedural success for ablation of PM PVCs is generally fair (60%-100%) and recurrence of similar morphology arrhythmias that require a repeat ablation procedure is common (approximately 5%–58%).[10, 14-17] Compared with the control group with point-by-point mapping, a higher efficiency and higher success rate in the duodecapolar catheter group may be attributed to the following aspects. Firstly, localization of PM PVCs foci relies mainly on accurate activation mapping of clinical PVCs, usually complemented with pace mapping, which is important for successful

ablation of such arrhythmias. Using a 20-pole mapping catheter with 2-mm interelectrode spacing can yield a greater electrophysiologic understanding of the earliest ventricular activation areas during PVCs and therefore a more efficient targeting of arrhythmia sources and exit sites is achievable. Potential ablation targets can be identified expeditiously and an ablation catheter can be directed to these sites. A more favorable outcome in the duodecapolar catheter group seems to be mediated by a more comprehensive treatment of PVC substrate. Secondly, making adequate catheter contact of catheter tip with the contracting muscle during systole is also essential for successful ablation. It was helpful to confirm adequate contact between the ablation catheter and the endocardial surface with fluoroscopy, mapping system geometry, and the quality of local electrograms. The high mapping density created by the duodecapolar catheter and subsequent earliest activation potentials with sharp initial signals are specific for avoiding poor contact. We also found that for a given targeted area, the near-field electrogram quality on the duodecapolar catheter was often superior to the ablation catheter. This may be due to the smaller size of sensing electrode and tighter bipole spacing of the duodecapolar catheter compared to larger electrode sizes of conventional ablation catheter. Moreover, it is not clear whether a transseptal or retrograde aortic approache is superior for ablation of PM PVCs. Published research investigating patients requiring ablation of PM PVCs tended to use the retrograde aortic approach, as in our series, and may offer greater catheter stability especially in the PPM while ablation for APM PVCs are better approached with a transseptal access.[14, 18, 19] In

the point-by-point mapping group, APM PVCs accounted for 80% of cases and inadequate catheter contact by the retrograde aortic approach may be an underlying reason for the lower acute ablation success rate. Finally, in patients with structurally normal hearts, the mechanism of PM PVCs tended to be focal, due to either triggered activity or enhanced automaticity.[19] The phenomenon of spontaneous PVCs with single QRS morphologies as well as unchanges in QRS morphology after ablation were seen in this cohort of patients with structurally normal heart, which is inconsistent with the literature that has reported almost half of patients with PM PVCs may exhibit spontaneous multiple QRS morphologies during an electrophysiology study.[14] Only single PVCs QRS morphologies observed in this study may lend credence to the hypothesis that PVC origin was from a single intrapapillary focus with conduction to a solitary breakout site,[15] and made it possible that less extensive ablation at sites of PVCs origin with excellent pace maps was successful in this study.

Apart from a duodecapolar catheter, ultra high-density mapping catheters frequently used include the Inquiry Afocus 20-pole deflectable spiral catheter (St. Jude Medical) and Pentaray (Biosense Webster, Diamond Bar, CA, USA). Koutbi et al.[20] used a 20-pole deflectable spiral catheter for ablation of PVCs originating from the left ventricular PM in four patients with structural heart disease, and they found that this mapping technique was more straightforward and feasible and complete PVCs abolition was achieved for all patients. However, technically, although its rounded shape is minimally arrhythmogenic, which makes it easier to map PVCs by avoiding mechanical ectopic beats, there is the

risk of the spiral being caught on the submitral apparatus and traumatizing this region of the left ventricle. Therefore, counterclockwise rotation or traction must be avoided and each time the catheter was caught in the chordae tendineae, a clockwise rotation easily extricated the spiral. Furthermore, the Pentaray shape is more arrhythmogenic and does complicate interpretation of the activation map and can be detrimental for PVC mapping, but has been shown to be accurate and expeditious in the mapping of complex reentrant atrial arrhythmias and atrial fibrillation.[4] As mentioned above, it may be advantageous to use a duodecapolar mapping catheter in the ventricle for rapid mapping and to guide ablation. On the one hand, due to the steerable and straight shape, it has less probability of arrhythmogenicity and damaging the submitral apparatus such as chordae tendineae. On the other hand, by using a 20-pole catheter with 2-mm interelectrode spacing for mapping, it can create a high sampling mapping density and multiple targets of earliest activation potentials can be identified rapidly and simultaneously. Matching pace maps can be generated within a given area with reference to the activation mapping target, and an ablation catheter can be directed to these sites previously tagged on electroanatomic mapping systems, which may significantly decrease mapping times compared to matched control cases using point-by-point mapping in current study. Finally, the increased mapping density created and high quality of the earliest activation potentials as well as near-field electrogram with sharp early signals identified by duodecapolar catheter, due to simultaneous recordings of local potential from different pairs of electrode with a relative short interelectrode distance, are specific for confirming

adequate catheter contact and further ablation.

Limitations

Firstly, the design of the study is retrospective and single-center in a relatively small sample size cohort with no structural heart disease, which was therefore subject to a myriad of biases, particularly selection bias and statistical power limitations. Hence, results from the current data need to be confirmed by further large-scale studies, which would be helpful to validate the reproducibility of the duodecapolar catheter mapping technique. Secondly, although the acute and intermediate clinical success rates in our series were satisfactory, long-term outcomes are needed to demonstrate feasibility and efficacy. Moreover, the technique was only employed using single ventricular access via retrograde transaortic approach in this study, and studies on double ventricular access obtained via double transseptal or double retrograde approach may be an area of future investigation optimizing the capability to manipulate the ablation catheter to the targeted multipolar electrode. Furthermore, intracardiac echocardiography (ICE), which may create a detailed ICE-based anatomic reconstruction of the LV, allows assurance of adequate catheter-tissue contact and optimal alignment of the catheter tip with the PM axis, although the post procedure echocardiographic appearance in our cases confirms that the lesions have indeed been generated on the PM. Finally, an ablation catheter with contact force (CF) capabilities was not utilized in this study, which not only provides CF information but also shows vector orientation of the catheter tip.

Conclusions

The present study provided insight into the mapping and ablation of PM PVCs using a duodecapolar catheter to perform ultra high-density mapping of LV endocardial activation in the structurally normal heart. Multipolar mapping with a duodecapolar catheter has the potential to facilitate identification of earliest activation potentials as well as pace mapping with a high procedural success rate, and should be considered in routine procedural mapping and ablation of PM PVCs.

Acknowledgements

None.

Disclosures

Conflicts of interest: None.

References

[1] Bogun F, Desjardins B, Crawford T, et al. Post-infarction ventricular arrhythmias originating in papillary muscles[J]. J Am Coll Cardiol, 2008,51(18):1794-1802.

[2] Prystowsky E N, Padanilam B J, Joshi S, et al. Ventricular arrhythmias in the absence of structural heart disease[J]. J Am Coll Cardiol, 2012,59(20):1733-1744.

[3] Latchamsetty R, Yokokawa M, Morady F, et al. Multicenter Outcomes for Catheter Ablation of Idiopathic Premature Ventricular Complexes[J]. JACC Clin Electrophysiol, 2015,1(3):116-123.

[4] Patel A M, D'Avila A, Neuzil P, et al. Atrial tachycardia after ablation of persistent atrial fibrillation: identification of the critical isthmus with a combination of multielectrode activation mapping and targeted entrainment mapping[J]. Circ Arrhythm Electrophysiol, 2008,1(1):14-22.

[5] Tung R, Nakahara S, Maccabelli G, et al. Ultra high-density multipolar mapping with double ventricular access: a novel technique for ablation of ventricular tachycardia[J]. J Cardiovasc Electrophysiol, 2011,22(1):49-56.

[6] Schiller N B, Shah P M, Crawford M, et al. Recommendations for quantitation of the left ventricle by two-dimensional echocardiography. American Society of Echocardiography Committee on Standards, Subcommittee on Quantitation of Two-Dimensional Echocardiograms[J]. J Am Soc Echocardiogr, 1989,2(5):358-367.

[7] Nguyen D T, Tzou W S, Sandhu A, et al. Prospective Multicenter Experience With Cooled Radiofrequency Ablation Using High Impedance Irrigant to Target Deep Myocardial Substrate Refractory to Standard Ablation[J]. JACC Clin Electrophysiol, 2018,4(9):1176-1185.

[8] Van Herendael H, Zado E S, Haqqani H, et al. Catheter ablation of ventricular fibrillation: importance of left ventricular outflow tract and papillary muscle triggers[J]. Heart Rhythm, 2014,11(4):566-573.

[9] Santoro F, Di Biase L, Hranitzky P, et al. Ventricular fibrillation triggered by PVCs from papillary muscles: clinical features and ablation[J]. J Cardiovasc Electrophysiol, 2014,25(11):1158-1164.

[10] Yokokawa M, Good E, Desjardins B, et al. Predictors of successful catheter ablation of ventricular arrhythmias arising from the papillary muscles[J]. Heart Rhythm, 2010,7(11):1654-1659.

[11] Yamashita S, Cochet H, Sacher F, et al. Impact of New Technologies and Approaches for Post-Myocardial Infarction Ventricular Tachycardia Ablation During Long-Term Follow-Up[J]. Circ Arrhythm Electrophysiol, 2016,9(7).

[12] Jais P, Maury P, Khairy P, et al. Elimination of local abnormal ventricular activities: a new end point for substrate modification in patients with scar-related ventricular tachycardia[J]. Circulation, 2012,125(18):2184-2196.

[13] Nayyar S, Wilson L, Ganesan A N, et al. High-density mapping of ventricular scar: a comparison of ventricular tachycardia (VT) supporting channels with

channels that do not support VT[J]. Circ Arrhythm Electrophysiol, 2014,7(1):90-98.

[14] Yamada T, Doppalapudi H, McElderry H T, et al. Electrocardiographic and electrophysiological characteristics in idiopathic ventricular arrhythmias originating from the papillary muscles in the left ventricle: relevance for catheter ablation[J]. Circ Arrhythm Electrophysiol, 2010,3(4):324-331.

[15] Yamada T, McElderry H T, Okada T, et al. Idiopathic focal ventricular arrhythmias originating from the anterior papillary muscle in the left ventricle[J]. J Cardiovasc Electrophysiol, 2009,20(8):866-872.

[16] Latchamsetty R, Yokokawa M, Morady F, et al. Multicenter Outcomes for Catheter Ablation of Idiopathic Premature Ventricular Complexes[J]. JACC Clin Electrophysiol, 2015,1(3):116-123.

[17] Good E, Desjardins B, Jongnarangsin K, et al. Ventricular arrhythmias originating from a papillary muscle in patients without prior infarction: a comparison with fascicular arrhythmias[J]. Heart Rhythm, 2008,5(11):1530-1537.

[18] Tilz R R, Makimoto H, Lin T, et al. In vivo left-ventricular contact force analysis: comparison of antegrade transseptal with retrograde transaortic mapping strategies and correlation of impedance and electrical amplitude with contact force[J]. Europace, 2014,16(9):1387-1395.

[19] Doppalapudi H, Yamada T, McElderry H T, et al. Ventricular tachycardia

originating from the posterior papillary muscle in the left ventricle: a distinct clinical syndrome[J]. Circ Arrhythm Electrophysiol, 2008,1(1):23-29.

[20] Koutbi L, Maille B, Peyrol M, et al. High-density mapping for catheter ablation of premature ventricular complexes originating from left ventricular papillary muscles: A case series[J]. Pacing Clin Electrophysiol, 2018,41(9):1071-1077.

Table 1 Baseline demographic and clinical characteristics in patients with PVCs arising from the papillary muscles stratified by duodecapolar catheter mapping

	Overall (n=11)	With duodecapolar catheter (n=6）	Without duodecapolar catheter (n=5）	P-value
Demographics				
Age,yrs	41 ± 18	31 ± 13	53 ± 16	**0.033**
Male,%	5 (45.5%)	2 (33.3%)	3 (60.0%)	0.567
BMI, kg/m^2	22.6 ± 2.2	22.1 ± 2.3	23.1 ± 2.3	0.466
History of PVCs,mths	26 ± 28	32 ± 34	18 ± 19	0.444
Echocardiography				
LAD, mm	33.2 ± 3.8	31.7 ± 4.5	35.0 ± 2.1	0.162
LVEDD, mm	46.6 ± 4.8	45.2 ± 3.8	48.2 ± 5.7	0.317
LVEF, %	63.0 ± 3.4	63.5 ± 4.0	62.4 ± 2.9	0.620
MR grade	1.4 ± 0.5	1.3 ± 0.5	1.4 ± 0.5	0.841
ECG and 24h-Holter ECG				
Intrinsic QRS duration, ms				
Total Heart beats	109601 ± 12170	105652 ± 16457	112892 ± 7140	0.352
Toal PVCs	20600 ± 10125	23020 ± 13475	18583 ± 7002	0.498
PVC burden,%	18.6% ± 8.2%	21.4% ± 10.7%	16.2% ± 5.4%	0.328

NSVT,%	7 (63.6%)	5 (83.3%)	2 (40.0%)	0.242
Laboratory test				
Serum creatinine, umol/L	73.9 ± 13.5	70.7 ± 7.6	77.8 ± 18.7	0.411
Hemoglobin, g/L	133.5 ± 12.9	131.7 ± 11.7	140.0 ± 14.1	0.324
NT-proBNP, pmol/L	57.3 ± 46.8	42.2 ± 24.4	75.3 ± 63.2	0.264
HsCRP, mg/L	0.8 ± 0.8	0.5 ± 0.4	1.1 ± 1.0	0.256
Comorbidities				
Hypertension	2 (18.2%)	1 (16.7%)	1 (20.0%)	0.727
Diabetes mellitus	1 (9.1%)	1 (16.7%)	0 (0%)	0.545
Hypercholesterolemia	2 (18.2%)	2 (33.3%)	0 (0%)	0.455
Congenital heart disease	1 (9.1%)	1 (16.7%)	0 (0%)	0.455
Medication treatments				
β-Blocker	6 (54.5%)	3 (50.0%)	3 (60.0%)	0.608
Propafenone	3 (27.3%)	1 (16.7%)	2 (40.0%)	0.545
Mexiletine	3 (27.3%)	3 (50.0%)	0 (0%)	0.182

The data are presented as the numbers (%) or the means ± SD. PVCs = premature ventricular contractions; BMI = body mass index; LAD = left atrial diameter; LVEDD = left ventricular end-diastolic diameter; LVEF = left ventricular ejection fraction; MR = mitral regurgitation; NSVT = nonsustained ventricular tachycardia; NT-proBNP = N-terminal pro-brain natriuretic peptide; hsCRP = high-sensitivity C-reactive protein

Table 2 Comparison of the procedural characteristics and ablation data between the papillary muscles PVCs patients in those with and without duodecapolar mapping

	With duodecapolar catheter (n=6）	Without duodecapolar catheter (n=5）	P-value
Abaltion procedure			
Procedure time (min)	95.3 ± 6.6	141.2 ± 12.3	**<0.001**
Fluoroscopy time (min)	14.1 ± 1.7	24.4 ± 5.4	**0.002**
Ablation data			
V-QRS (ms)	32.3 ± 3.9	25.4 ± 2.8	**0.008**
Perfect/Good pacemaps, n (%)	6 (100.0%)	3 (60.0%)	0.182
Number of ablation applications	6.8 ± 1.9	14.8 ± 3.6	**0.001**
Total ablation duration (min)	6.1 ± 3.0	15.8 ± 4.7	**0.006**
Average ablation output (W)	33.3 ± 2.6	33.0 ± 2.7	0.841
Average Impedance drop (Ω)	10.8 ± 1.8	9.4 ± 1.7	0.209
Origin			
APM, n (%)	2 (33.3%)	4 (80.0%)	0.242
PPM, n (%)	4 (66.7%)	2 (40.0%)	0.567
Successful ablation , n (%)	6 (100.0%)	3 (60.0%)	0.182
Years of follow-up, months	9.8 ± 3.5	9.6 ± 3.3	0.912

The data are presented as the numbers (%) or the means ± SD. PVCs = premature ventricular complexes; V-QRS = earliest activation time relative to QRS onset during PVCs; APM = anterior papillary muscles; PPM = posterior papillary muscles

Legends

Figure 1. A and B: Ultra high-density mapping of left ventricle using the linear duodecapolar catheter showed the site of earliest ventricular activation during clinical PVCs was located at the APM, which was marked with the red dot. C: Intracardiac electrogram during PVCs demonstrated the earliest ventricular potential recorded at DD 1-2 (54 ms pre-QRS), and they conducted upward along the linear catheter. D: Pacing from a site with earliest ventricular activation seen on DD 1-2 revealed a 12/12 perfect pace map match. E. Radiofrequency energy was delivered to the target site of the red dot with 52 ms pre-QRS and PVCs terminated following transient monomorphic non-sustained ventricular tachycardia. PVCs = premature ventricular contractions; APM = anterior papillary muscles; DD = duodecapolar catheter.

Figure 2. A and B: A 3-dimensional ventricular activation map during clinical PVCs guided by the linear duodecapolar catheter showed ventricular excitation sites in the PPM of the left ventricle. The red dot indicated the site where the earliest ventricular excitation potential was recorded during PVCs. The yellow dots on the proximal duodecapolar catheter indicated the His-bundle site. C: Intracardiac electrogram recorded with a duodecapolar catheter during the PVCs (left panel) showed the earliest local ventricular potential preceding the QRS onset by 42 ms located at DD 9-10 (asterisk), and they conducted upward and downward along the linear catheter, respectively. During the sinus beat (right panel), the proximal DD 19-20 and DD 18-19 (red arrow) recorded his bundle potentials. D: Pacing from a site with earliest ventricular

activation seen on DD 9-10 demonstrated a 12/12 perfect pace map match. E. We delivered radiofrequency energy to the target site of the red dot with 38 ms pre-QRS and terminated PVCs. PVCs = premature ventricular contractions; PPM = posterior papillary muscles; DD = duodecapolar catheter.

Figure 1.

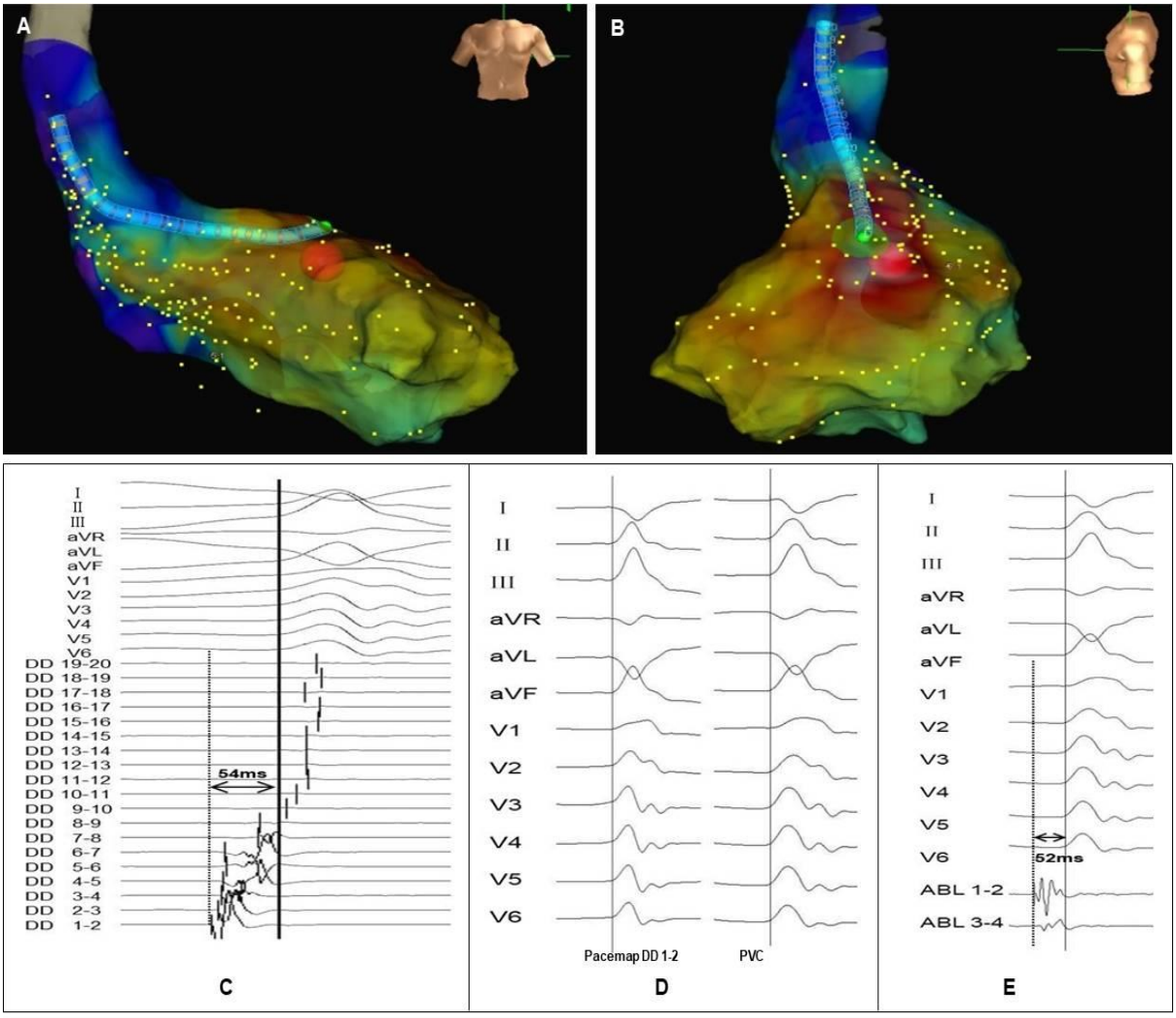
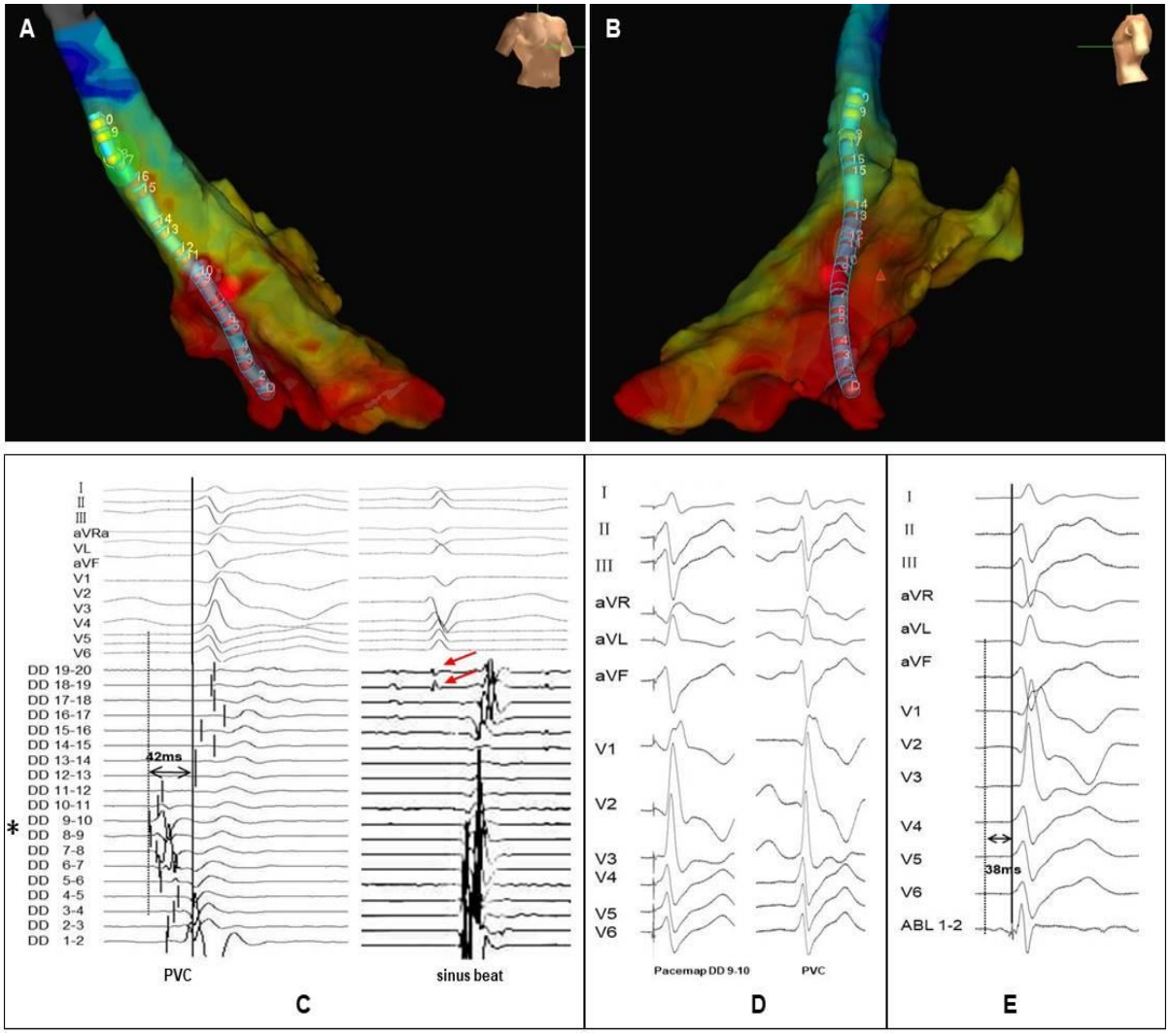

A
B
I
II
III
aVR
aVL
aVF
V1
V2
V3
V4
V5
V6
DD 19-20
DD 18-19
DD 17-18
DD 16-17
DD 15-16
DD 14-15
DD 13-14
DD 12-13
DD 11-12
DD 10-11
DD 9-10
DD 8-9
DD 7-8
DD 6-7
DD 5-6
DD 4-5
DD 3-4
DD 2-3
DD 1-2
54ms
C
Pacemap DD 1-2
PVC
D
52ms
ABL 1-2
ABL 3-4
E

Figure 2.


A
B
I
II
III
aVRa
VL
aVF
V1
V2
V3
V4
V5
V6
DD 19-20
DD 18-19
DD 17-18
DD 16-17
DD 15-16
DD 14-15
DD 13-14
DD 12-13
DD 11-12
DD 10-11
DD 9-10
DD 8-9
DD 7-8
DD 6-7
DD 5-6
DD 4-5
DD 3-4
DD 2-3
DD 1-2
42ms
PVC
sinus beat
C
I
II
III
aVR
aVL
aVF
V1
V2
V3
V4
V5
V6
Pacemap DD 9-10
PVC
D
I
II
III
aVR
aVL
aVF
V1
V2
V3
V4
V5
V6
ABL 1-2
38ms
E