

Long-term study on electrophysiological characteristics and catheter ablation of idiopathic ventricular arrhythmias originating from the left ventricular posterior papillary muscles guided by intracardiac ultrasound

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Abstract

Background: This study aimed to investigate the electrophysiological characteristics of idiopathic ventricular arrhythmias (VAs) originating from the left ventricular posterior papillary muscles (LPPM) and explore the efficiency of catheter ablation using three-dimensional intracardiac ultrasound technology.

Methods: Twenty-seven cases of premature ventricular contraction/ventricular tachycardia (PVC/VT) originating from the left ventricular posterior papillary muscles were recorded from July 2015 to June 2019 in the Central Hospital of Shengli Oil Field and the First Affiliated Hospital of Zhengzhou University. Electrophysiological mapping and radiofrequency catheter ablation (RFCA) were performed using three-dimensional intracardiac ultrasound technology. The characteristics of the body surface and intracavity electrocardiogram were analyzed. All cases were followed up for 24 months after the operation.

Results: The VAs of all 27 cases were successfully eliminated by catheter ablation. QRS complexes were observed with a right bundle branch block (RBBB) pattern and a steep slope in the initial segment. Lead I appeared with an Rs pattern, and inferior leads (lead II, III, and aVF) were usually with an S wave. The lead aVR appeared with a qR pattern, while the R wave was commonly found in aVL. The main wave in leads V₁-V₃ was positive but negative in V₅ and V₆.

Conclusion: Ventricular arrhythmias originating from the left ventricular posterior papillary muscles have similar electrophysiological characteristics. The origin site was accurately located using three-dimensional intracardiac ultrasound technology. Catheter ablation effectively eliminated VAs.

KEYWORDS

catheter ablation, papillary muscles, three-dimensional ultrasound, ventricular arrhythmia

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1 | INTRODUCTION

Idiopathic premature ventricular contraction/ventricular tachycardia (PVC/VT), which originates from specific parts, has been a popular topic of research in the field of cardiac electrophysiology in recent years. With the advancement in technology and development of new instruments, such as pressure monitoring technology, as well as a better understanding of ventricular arrhythmia, the research on PVC/VT has become more extensive. In previous studies, for PVC/VT originating from the left ventricular papillary muscle, it was considered that this type of arrhythmia had some electrophysiological characteristics (Chang et al., 2016; Keating et al., 2014). However, due to considerable variation in the structure of the papillary muscles, performing catheter ablation was difficult, and there was a lack of effective means to confirm it (Seiler et al., 2009). In this study, three-dimensional electroanatomical mapping and intracardiac echocardiography were used to study the characteristics of the body surface and intracardiac electrogram of PVC/VT originating from the left posterior papillary muscle (LPPM), to evaluate the effectiveness and safety of catheter ablation for such arrhythmias.

2 | STUDY SUBJECTS AND RESEARCH METHODS

2.1 | Study subjects

From July 2015 to June 2019, five hundred and sixteen patients with ventricular arrhythmia, to undergo radiofrequency ablation, were treated in the Shengli Oilfield Central Hospital and the First Affiliated Hospital of Zhengzhou University. Relevant examinations were routinely performed before ablation, and organic heart disease and other diseases that could cause arrhythmias, such as hyperthyroidism and electrolyte disorder, were excluded through imaging examination and serological detection. Additionally, diseases that could lead to the patients' intolerance to surgery, such as severe heart failure and severe infection, were excluded. If transthoracic echocardiography indicated that the left ventricular end-diastolic diameter was >55 mm or showed abnormal ventricular wall motion, further magnetic resonance (MR) scanning was performed to rule out organic heart disease. Antiarrhythmic drugs were stopped for at least five half-lives before ablation. Patients taking amiodarone needed to stop taking amiodarone for 3 months before radiofrequency ablation.

Among the five hundred and sixteen patients, thirty-six patients had organic heart diseases, such as dilated cardiomyopathy, hypertrophic cardiomyopathy, and myocardial infarction. Among the remaining four hundred and eighty patients, fifty-six patients could not stably induce PVC/VT during catheter ablation. Therefore, a total of four hundred and twenty-four patients underwent cardiac electrophysiological examination and radiofrequency ablation. Among all patients who underwent radiofrequency ablation, twenty-seven patients confirmed that their ventricular arrhythmia originated from

LPPM. In addition, twenty-one patients with ventricular arrhythmias originated from the left posterior branch (LPF) were included in the study as a control group.

2.2 | Research methods

Patients with PVC underwent radiofrequency ablation induced by premature systolic stability. When the number of premature beats was less, intravenous isoproterenol was administered to induce ventricular premature beats. The VT patients routinely needed right ventricular electrodes (Daig, SJM), and radiofrequency ablation was performed only after the ECG physiological stimulation could induce tachycardia consistent with the primary morphology.

2.2.1 | Creating the anatomical model

All patients underwent three-dimensional intracardiac ultrasound catheter (10F Soundstar, Johnson & Johnson) analysis and three-dimensional electroanatomical mapping (Carto 3, Johnson & Johnson). The right and left ventricular models were established using ultrasound; the morphologies of the left anterior papillary muscle and the left posterior papillary muscle were also constructed, and the number of left posterior papillary muscle bundles was recorded.

2.2.2 | Mapping and ablation

The Navistar SMARTTOUCH catheter (Johnson & Johnson) was applied to the left ventricle for activation mapping for a PVC/VT attack. During the operation by catheter ablation, 23 patients underwent a retrograde approach through the aorta, and the atrial septum was punctured through the right femoral vein for four patients under ultrasound guidance due to a poor retrograde approach to enter the left ventricle from the left atrium. The mapping process used the hotspot tracking method, in which the pressure at each point was controlled at 5–15 g (approx.) to avoid poor catheter-tissue contact or excessive compression of the myocardium. ECG morphology mainly recorded the time course, the direction of the main wave, and the morphology of the QRS complex. Intracardiac electrocardiogram mainly recorded the time course, starting vector direction, and morphological characteristics of the effective target local action potential (LAT) leading to the earliest QRS wave starting point.

The earliest activation point was mapped as the origin of tachycardia, and the characteristics of the local potential were recorded. Ablation was attempted at the earliest spot. The ablation parameters included power at 35 W and saline perfusion at 17 ml/min. When the premature beats stopped or tachycardia terminated, the ablation was consolidated for at least 40 s, and the location of the effective target of the final ablation was confirmed synchronously by three-dimensional ultrasound. After ablation, the primary arrhythmia disappeared, and the intravenous drip of isoproterenol and repeated

ventricular stimulation were observed for more than 30 min. When arrhythmia was not induced, the operation was considered to be a successful one. If repeated mapping and ablation were not possible, the ablation was considered to be a failure.

2.2.3 | Follow-up

All patients were followed up for 24 months. A standard twelve-lead electrocardiogram (ECG) was performed immediately after the operation and on the following day. An ambulatory electrocardiogram (Holter) was performed for 24 h after 3, 6, 12, and 24 months. Analyze the ECG results and clinical symptoms of patients to confirm whether there was ventricular arrhythmia.

2.3 | Statistical analysis

The baseline characteristics and statistical data of the cases were analyzed by the SPSS 23.0 statistical software. The enumeration data were expressed by rate or component ratio, and the measurement data were expressed by $(\bar{x} \pm s)$ or M (Q). Chi-squared test was used for the comparison of enumeration data, *t*-test, and rank sum test were used for the comparison of measurement data. *p* value <.05 was considered to indicate statistical significance.

3 | RESULTS

3.1 | Baseline characteristics

The 27 patients in the LPPM group accounted for 6.4% (27/424) of the total number of idiopathic ventricular arrhythmias. Among them, 21 cases had symptoms of discomfort to varying degrees, including palpitation, dizziness, and chest tightness, but no syncope. The symptoms of the patients in the LPF group mainly included palpitation, and one case had syncope. Both groups took at least two kinds of oral medication before the operation, which included β -receptor blockers; antiarrhythmic drugs had poor effects.

In the LPPM group, the left ventricular end-diastolic diameter (LVEDd) was >55 mm in five patients, and the left ventricular ejection fraction (EF) was <55% in four patients. MRI scanning, combined with other examinations, provided no evidence of any organic heart disease other than the primary disease found. In the LPF group, two cases also had ventricular enlargement and a decreased ejection fraction without other causes. Considering that ventricular enlargement and decline of cardiac function were related to primary ventricular arrhythmia, the results suggested that the primary disease had induced cardiac function damage, which was an important indication of the intervention of arrhythmia.

Among the 27 patients in the LPPM group, men accounted for 59.3% (16/27), with an average age of 41 ± 16 years. PVC was the main type of arrhythmia, accounting for 77.8% (21/27). Among the

TABLE 1 Baseline characteristics

Item	LPPM group	LPF group	<i>p</i>
Cases	27	21	-
Age (years)	41 ± 16	19 ± 17	<.01
Male	59.3%, 16/27	80.9%, 17/21	<.01
LVEDD (mm)	49.8 ± 6.6	48.9 ± 3.9	>.05
LVEF (%)	63.0 ± 9.0	61.6 ± 7.4	>.05
Arrhythmia type (PVC, %)	77.8%, 21/27	9.5%, 2/21	<.01

patients in the LPF group, men accounted for 80.9% (17/21), with an average age of 19 ± 17 years. The main type of arrhythmia was VT (90.5%, 19/21). There was no significant difference in LVEDd and EF between the two groups, but there were significant differences in average age, gender ratio, and the type of arrhythmia (Table 1).

3.2 | ECG characteristics

The QRS wave of ECG in the LPPM group showed a right bundle branch block pattern (RBBB), the ECG axis deviated to the left, and the average QRS wave duration was 147 ± 12 ms. In the limb leads of the LPPM group, lead I showed rS or RS type. In the inferior wall leads (II, III, and aVF), II and aVF leads were rS type, but the III leads of two patients were Rs type. The remaining 25 patients showed rS type in lead III, and an obvious notch was often seen (15/27). aVR leads showed characteristic qR type; AVL leads were mainly positive, and small s waves (voltage ≤ 0.1 mV) were observed at the end; however, eight patients showed Rs (6/8) or rS (2/8) (the possible reason was related to the change in the exit site from the PM into the left ventricle of ventricular premature beats caused by the position variation of Moderator band. If the exit site from the PM into the left ventricle was closer to the septal side, the deeper the S wave was). The directions of leads I, II, and aVF in the LPF group were similar but leads III were rS type, the inferior wall lead had no obvious notch, and the aVR lead also had the characteristics of qR type.

For precordial leads, in the LPPM group, leads V_1 and V_2 were dominated by R wave, and a notch was found. Small q waves (16/27) could be seen in most of the initial segments of lead V_1 , and most of them were Rsr or R type (rsR/Rsr or R = 5/22), that is, they showed the left "rabbit ear" sign. In the LPF group, the V_1 lead showed the right "rabbit ear" sign (rsR/Rsr or r = 14/7). In the LPPM group, a few V_3 leads showed Rs type (7/27), and one case showed rS type with minimal r wave. In seven cases, the r' wave was observed at the end of the QRS wave, which had certain characteristics. Both V_5 and V_6 leads were dominated by the S wave, and the smaller r wave could be seen. The shift in the precordial leads in the two groups was mostly in the leads V_2 - V_4 (Figure 1).

Another typical feature of the LPPM group, whether in limb leads or chest leads, is that the slope of the initial segment of the QRS wave is large. According to the average value of the QRS time history (147 ms), the voltage in the front and back half of the QRS

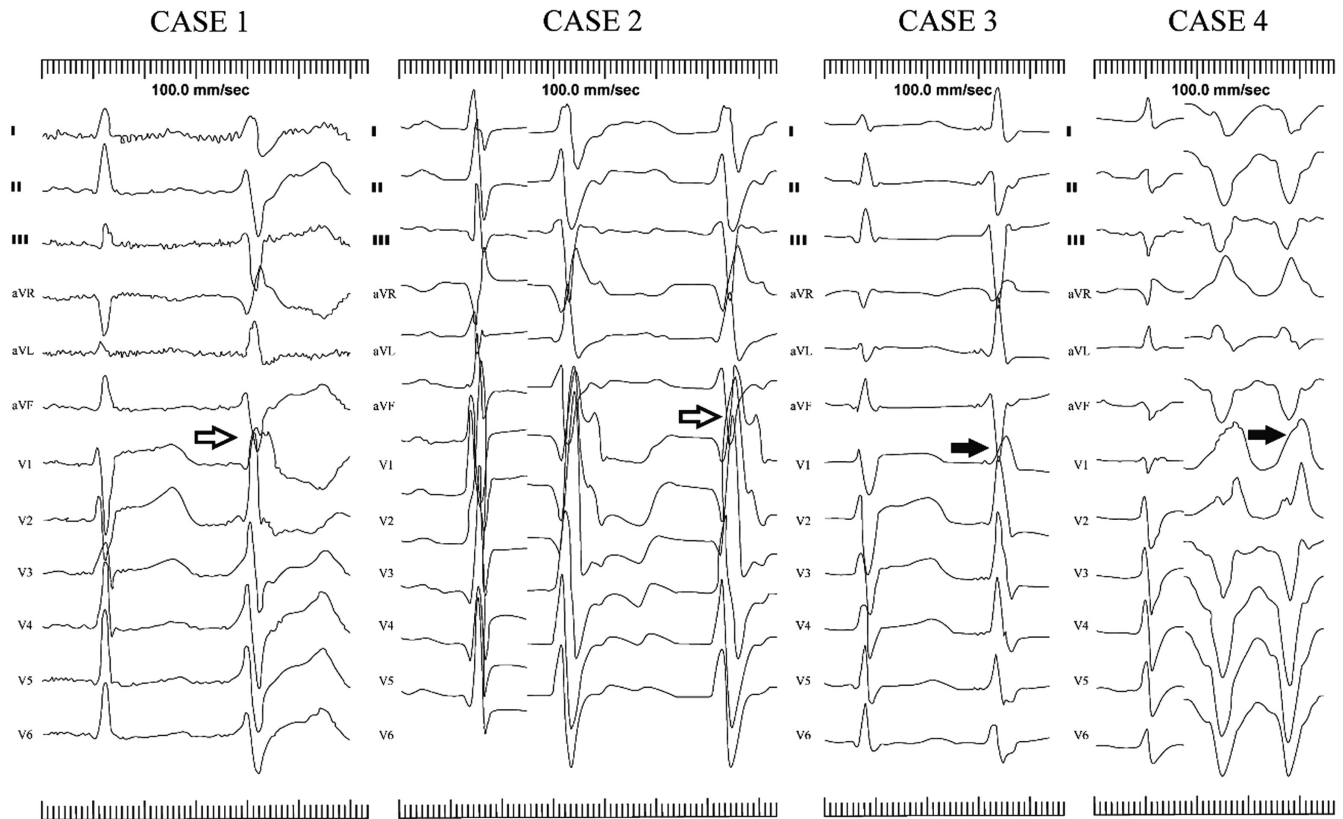


FIGURE 1 Shown were the ECG characteristics. Cases 1 and 2 were PVC and VT cases of LPPM origin, and cases 3 and 4 were PVC and VT cases of LPF origin. All are right bundle branch block patterns. Lead I was rS or Rs type, the main wave of inferior wall lead (II, III, and aVF) was mainly negative, aVR lead was characteristic qR type, and aVL lead was mainly positive. The most important difference between the two groups was that the left “rabbit ear” sign was common in V₁ of the LPPM group and the right “rabbit ear” sign in V₁ of the LPF group. The origin of LPPM shifts from precordial leads V₂ to V₄. R ‘waves were often seen in leads V₃, whereas deeper S waves were seen in leads V₅ and V₆

TABLE 2 Initial and terminal voltage (70ms) of QRS waves

Lead	Voltage (mV, initial 70ms)	Voltage (mV, terminal 70ms)	p
I	0.85±0.12	0.42±0.09	<.01
II	1.62±0.31	0.57±0.17	<.01
III	0.74±0.26	0.69±0.21	>.05
aVR	0.87±0.29	0.76±0.34	>.05
aVL	0.79±0.32	0.82±0.25	>.05
aVF	1.47±0.37	0.56±0.08	<.01
V1	0.78±0.27	0.64±0.19	<.05
V2	1.26±0.45	0.65±0.33	<.01
V3	1.29±0.41	0.44±0.11	<.01
V4	1.86±0.47	0.72±0.23	<.01
V5	1.94±0.52	0.68±0.20	<.01
V6	1.75±0.57	0.48±0.12	<.01

wave of each lead was measured, that is, the voltage in the first 70ms and the last 70ms. It was found that the voltage fluctuated more in the initial section, suggesting more rapid depolarization (Table 2).

3.3 | Mapping and ablation

During the mapping process in this study, it was found that the papillary muscle in the posterior left ventricular group showed three forms in the number of initial heads, which included single head, double heads, and triple heads. Most of the 27 cases were double heads type (25 cases), one was single head type, and one was triple heads type (Figure 2).

During excitation mapping, it was usually faster to confirm that the origin was the left posterior papillary muscle. However, it took a long time for some cases to find the earliest origin point by further fine mapping. This was because the papillary muscle bundle was columnar and might have been located at the top, in the middle, or at the base of different muscle bundles. Among the 27 patients, the final target was located at the top in four cases, in the middle in 15 cases, and at the base in eight cases. At the effective ablation target, the local bipolar potential showed certain characteristics: the initial segment potential was sharp, and its shape was similar to the bundle branch potential of the Purkinje system. In this study, this was called the “papillary muscle potential” (18/27). In the sinus rhythm, more than half of the bundle branch potentials could not be recorded simultaneously (11/18). Compared with

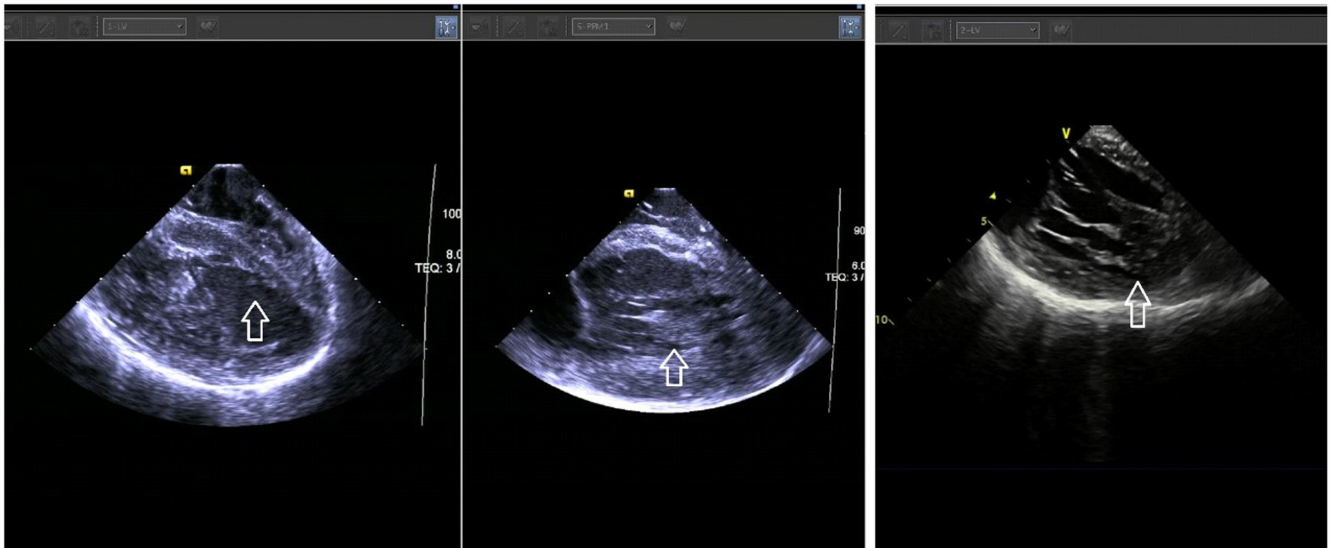


FIGURE 2 Shown were the different papillary muscle morphologies. The left, middle, and right figures show the different forms of the left posterior papillary muscle; single head, double heads, and triple heads (at the arrow)

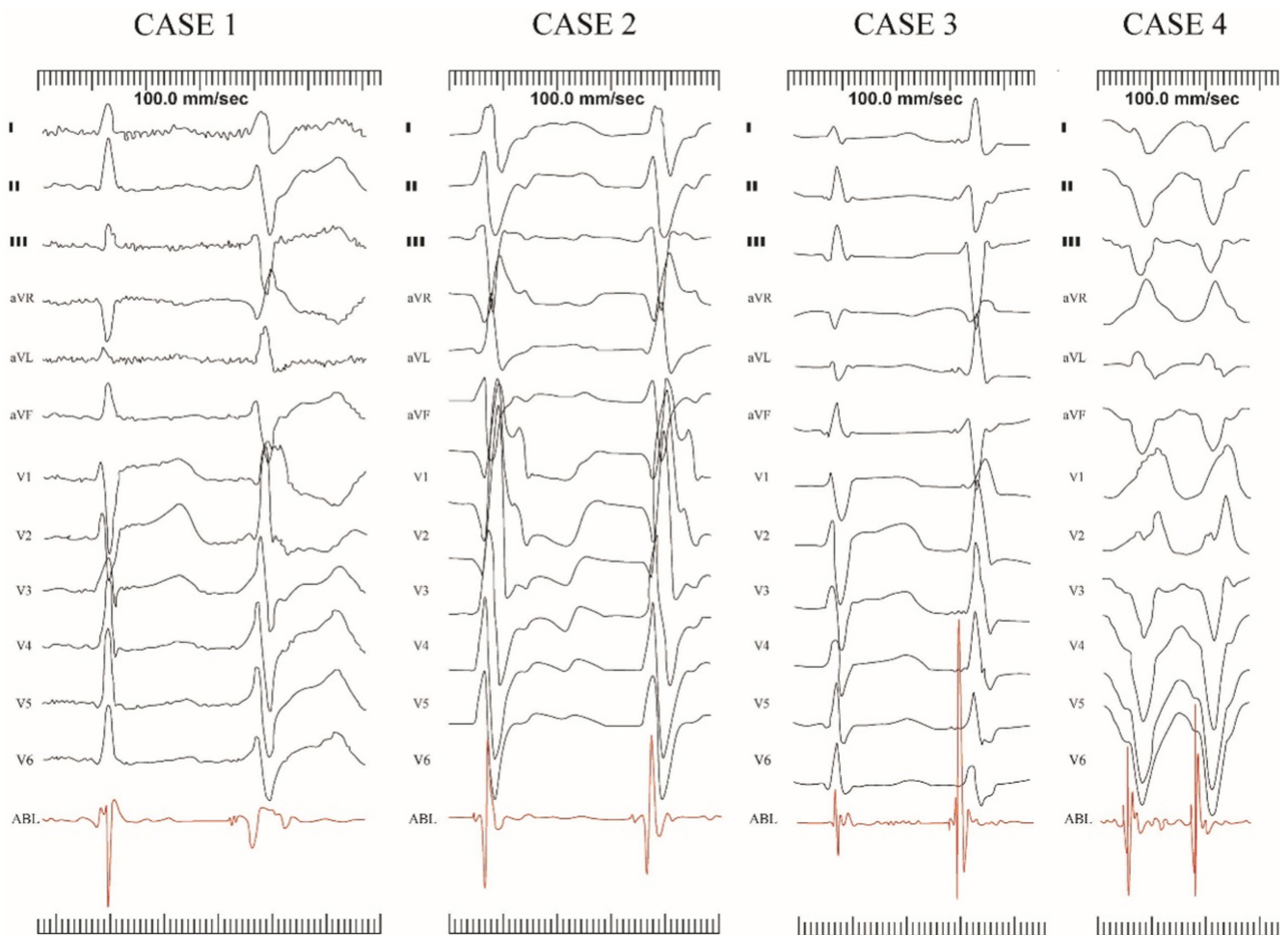


FIGURE 3 Shown was the bipolar potential at the target. Cases 1 and 2 were PVC and VT cases of LPPM origin, and cases 3 and 4 were PVC and VT cases of LPF origin. In the LPPM group, a sharp potential, similar to a bundle branch potential or “papillary muscle potential,” can be seen at the effective ablation target. In the LPF group, the bundle branch potential (P potential) was constant in front of the V wave

the sinus rhythm, potential reversal (14/27) was often observed under arrhythmia (Figure 3). In the LPF group, because the site of origin was located at the left posterior branch, obvious bundle branch potentials were recorded in the sinus rhythm and tachycardia, and typical P1 and P2 potentials were recorded in some cases in tachycardia.

A pressure monitoring catheter was used during ablation. This study found that the ablation of the left posterior papillary muscle did not need high pressure. The average pressure during ablation was 4–10 g (approx.), and the ablation time was 45 ± 29 s. The onset of arrhythmia was effectively terminated in all the patients. Additionally, the ablation in the ultrasonic window was observed to ensure that the tip of the catheter was close to the papillary muscle. There were no complications such as pericardial tamponade during and after the operation.

3.4 | Follow-up

During the 24-month follow-up period, no patient used antiarrhythmic drugs. Of all the 27 patients, 26 patients had no primary symptoms and ventricular arrhythmia. Only one patient had ventricular premature beats with different morphology from the primary ventricular premature beats, and the 24-h ambulatory electrocardiogram of the patient showed that there were <500 ventricular premature beats.

4 | DISCUSSION

Ventricular arrhythmia, originating from the left posterior papillary muscle, has become common for the diagnosis and treatment of arrhythmia in recent years. Ventricular arrhythmias originating from the left posterior papillary muscle are frequently sensitive to catecholamines, noninducible by programmed stimulation, and non entrainable, often requiring isoproterenol for induction, which suggests triggered activity or abnormal automaticity as the electrophysiological mechanism (Abouezzeddine et al., 2012). It was postulated that decreased Purkinje-ventricular coupling at the PM affects the electrical loading of the Purkinje cells by the neighboring myocardium, and might facilitate automaticity or triggered activity. This study found that ventricular arrhythmias originating from the left posterior papillary muscle accounted for 6.4% of all idiopathic ventricular arrhythmias. This study suggested that male patients were more common in the overall population. The onset was mainly found in middle-aged and young individuals, and the youngest was only 8 years old. The premature beat is the main form of arrhythmia. In contrast, ventricular arrhythmias originating from the left posterior branch generally occur in young men. This study suggested that reentrant ventricular tachycardia was more likely to form at the left posterior branch of the cardiac conduction system. In contrast, at the papillary muscle, premature beats caused by abnormal impulse formation were the main manifestations. Arrhythmias originated

from the LPPM, if not treated, can cause cardiomyopathy, which is characterized by left ventricular enlargement and decreased ejection fraction (Yokokawa et al., 2013).

Previous studies have confirmed that the left posterior papillary muscle of different patients shows different morphology (Enriquez et al., 2017; Farzana et al., 2015). Traditionally, the posteromedial papillary muscle is described as being relatively medial compared with the anterolateral papillary muscle. Therefore, in the form of the QRS wave, it showed corresponding ECG vector characteristics. For example, it showed RBBB pattern, lead I showed an RS pattern, the main wave direction of inferior wall lead was negative, the main wave direction of AVR lead was positive, and the main wave direction of V_5 and V_6 leads was negative. Compared with the origin on the left posterior branch, lead III tended to be negative, and part of the origin of LPPM was positive, as the left posterior branch was closer to the interval.

Regarding chest lead migration, theoretically, since the LPPM is more inclined to the ventricular sidewall, migration should be earlier than the left posterior branch ventricular tachycardia. However, in this study, the difference between the two was not obvious. When considering the origin of the left posterior branch, the origin point was mostly in the middle and posterior segment of the bundle branch, close to the apex of the heart, so the negative component of lead V_4 - V_6 was more significant, offsetting the influence of proximity interval on the displacement.

On this basis, as the left posterior papillary muscle was accompanied by the posterior group of the left posterior branch, it had unique characteristics: the initial segment of the QRS wave was sharp, suggesting that the depolarization speed in the initial stage of action potential was greater, which might have been related to the faster activation of bundle branches (Al'Aref et al., 2015). Since it was far from the bundle branch trunk, the QRS wave duration of arrhythmia originated from the LPPM was significantly greater than that originated from the LPF, usually greater than 120 ms, which was still a part of wide QRS arrhythmia (Nogami et al., 2000). Therefore, the origin of the left posterior papillary muscle was directly determined by the above characteristics and the qR morphology of aVR lead.

The mapping of the left posterior papillary muscle was difficult. Since there were considerable differences in the morphology of papillary muscles among individuals, morphological variations could be single-, double-, or triple heads, and the muscle bundle was free, which made mapping difficult. In this study, the final effective target was most common in the middle of the papillary muscle (55.6%, 20/36), followed by the base, and originated lesser from the top of the muscle bundle. By using intracardiac ultrasound, we not only established the papillary muscle model by operation but also observed the papillary muscle structure in real-time in the ultrasonic window, as well as the catheter-tissue contact and correct orientation of the catheter tip, to determine the position of the effective ablation target accurately. Intracardiac ultrasound was very convenient for mapping, which was similar to some contents studied by Enriquez and other researchers (Enriquez et al., 2018).

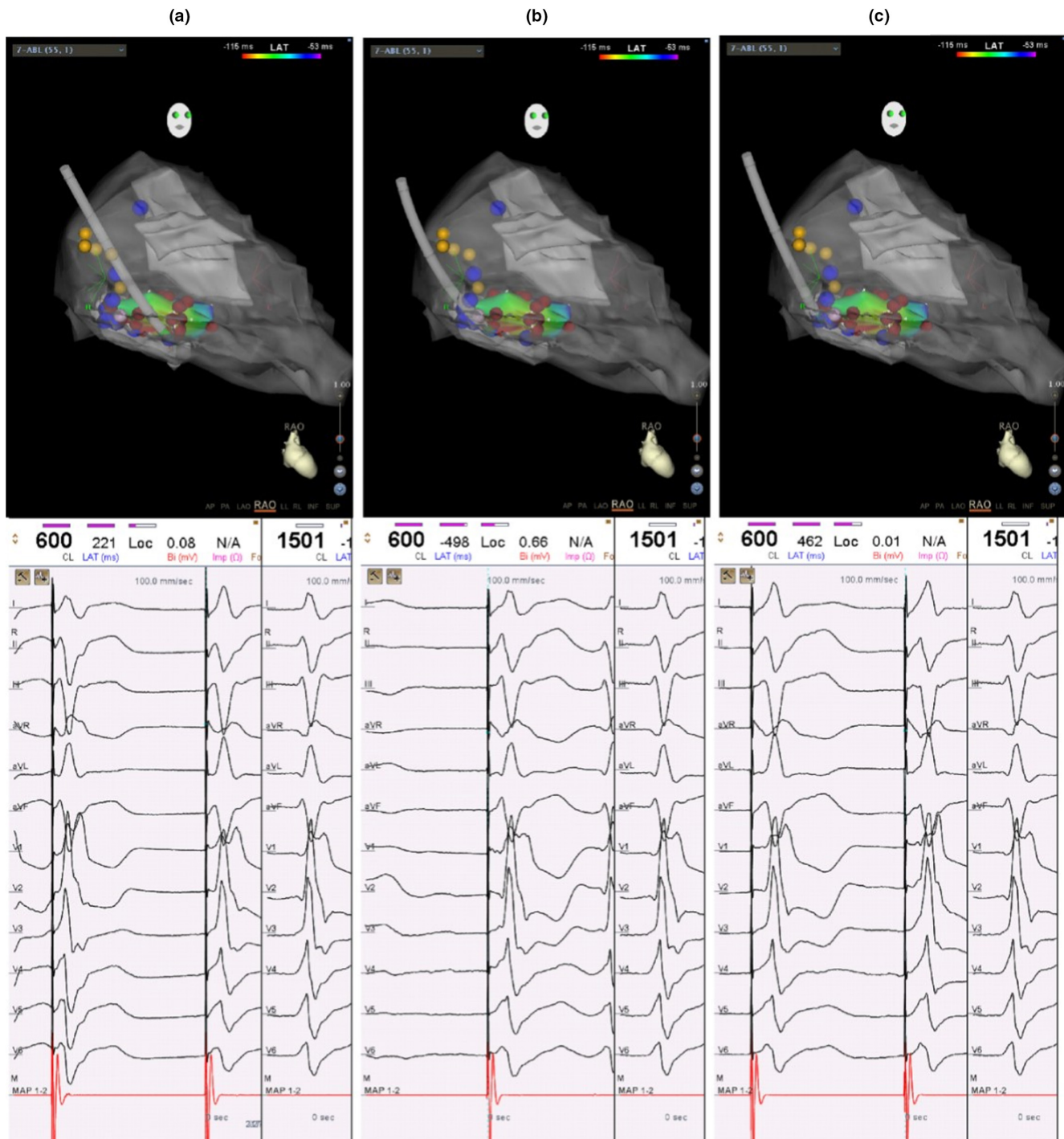


FIGURE 4 Morphology of QRS wave during pacing papillary muscle. (a, b and c) represented pacing at the bottom, end, and top of papillary muscle base respectively. It could be seen that the QRS waveform state of ECG during pacing was consistent with that of primary premature beat. It was suggested that there was no significant difference in QRS wave morphology during pacing for ventricular premature beats originated from different parts of the same papillary muscle head, so pacing mapping was not suitable for papillary muscle ventricular arrhythmia mapping

This study also found that pacing mapping was unreliable for PVC/VT of papillary muscle origin (Itoh & Yamada, 2018). Pacing mapping was performed at the top, terminal, and base of papillary muscle during ablation. It could be seen that the QRS waveform of pacing ECG was consistent with that of primary ventricular premature beat. This study suggests that on the same muscle bundle,

no matter where the origin point was, the final form of arrhythmia QRS wave tends to be consistent. Therefore, detailed mapping and potential identification along the muscle bundle were particularly important. On the contrary, it was confirmed that pacing mapping could not obtain reliable targets in this type of arrhythmia. The reason might be that the tendon did not contain cardiomyocytes and

had no conductivity, so the bioelectrical activity on the papillary muscle could only be transmitted to the ventricular muscle through the base, that was, the efferent site (outlet) was single, so the form of QRS wave was also fixed (Figure 4).

By using three-dimensional intracardiac ultrasound, it could be determined whether the ablation catheter was well-attached. The PVC/VT, originating from the left posterior papillary muscle, did not need high pressure and long discharge time to achieve the ideal effect. Excessive ablation at the papillary muscle might have caused poor papillary muscle function or ventricular fibrillation (Muenkler et al., 2021; Nishiyama et al., 2017). Moreover, this study found that there were sharp potential and potential reversal at the ablation target, which helped to identify the effective target.

5 | RESEARCH LIMITATIONS

The number and distribution of diseases in this study might have been affected to some extent, which might have interfered with the baseline characteristics. In the follow-up after ablation, only one 24-h ambulatory ECG evaluation was used, rather than the placement of electronic devices or continuous 7-day ambulatory ECG. Therefore, the recurrence of ventricular arrhythmia might be underestimated.

6 | CONCLUSION

Ventricular arrhythmia originated from the left posterior papillary muscle have unique electrocardiographic characteristics, and their recognition is very important for pre-procedural planning. Compared with fascicular arrhythmias, an rsR' pattern (right "rabbit ear") in lead V₁ is characteristic of fascicular arrhythmias, whereas Rsr or R pattern (left "rabbit ear") is present in LPPM VAs. In addition, fascicular arrhythmias typically have a small q wave in either lead I or aVL (qR or qRs), whereas this pattern is not present in LPPM VAs. Another typical feature of the LPPM VAs is that the slope of the initial segment of the QRS wave is large. Three-dimensional mapping, guided by intracardiac ultrasound to find the characteristic earliest potential, accurately located the point of origin. Catheter ablation effectively terminated arrhythmia attacks, and its safety was demonstrated.

AUTHOR CONTRIBUTION

Xiangfei Liu and Jin Wang conceived the idea and conceptualized the study. Yanwei Gong and Changmin Wei collected the data. Jin Wang and Yanwei Gong analyzed the data. Xiangfei Liu and Yanwei Gong drafted the manuscript, and then, Jin Wang and Changmin Wei reviewed the manuscript. All authors read and approved the final draft.

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None.

CONFLICT OF INTEREST

The authors declare that they have no competing interests.

DATA AVAILABILITY STATEMENT

All data generated or analyzed during this study are included in this article.

ETHICAL APPROVAL

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The study was approved by the Shengli Oilfield Central Hospital and the First Affiliated Hospital of Zhengzhou University.

CONSENT TO PARTICIPATE

Informed consent was obtained from all individual participants included in the study.

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