



Original article

Impact of catheter ablation of ventricular tachycardia in patients with prior myocardial infarctions

Masato Fukunaga, MD*, Masahiko Goya, MD, Kenichi Hiroshima, MD, Kentaro Hayashi, MD, Masatsugu Ohe, MD, Yu Makihara, MD, Michio Nagashima, MD, Yoshimori An, MD, Shinichi Shirai, MD, Kenji Ando, MD, Hiroyoshi Yokoi, MD, Masashi Iwabuchi, MD

Department of Cardiology, Kokura Memorial Hospital, Japan

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ABSTRACT

Background: Catheter ablation can reduce episodes of ventricular tachycardia (VT) after myocardial infarction (MI). However, the optimal endpoint of the ablation procedure remains unclear.

Methods: Fifty-one consecutive patients who received catheter ablation for VT after MI were included. The procedures targeted the isthmus of all the induced, sustained VTs. When the patients with induced VTs were hemodynamically stable, radiofrequency energy was delivered at the mid-diastolic potential recording site during VT. When the patients with VTs were hemodynamically unstable, the critical channel was identified at the delayed potential recording site, showing a good pace map, with a long stimulus-QRS interval. We delivered radiofrequency energy along the identified isthmus and across the exit of the circuit.

Results: At the end of the procedure, all VTs became non-inducible in 30 patients (59%) and some VTs were inducible in 21 patients (41%). During a mean of 40 ± 29 months of follow-up, no VT or ventricular fibrillation recurred in 24 patients (80%) in the non-inducible group and in 12 patients (57%) in the inducible group, respectively ($P=0.03$). The identification of the channel during VT mapping tended to associate with no recurrence, although the difference was not statistically significant ($P=0.2$). Fourteen patients (27%) died during the follow-up period, mostly due to non-cardiac causes.

Conclusions: The catheter ablation targeting the isthmus of prior-MIVT and non-inducibility at the end of the procedure can provide a satisfactory follow-up result.

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1. Introduction

For patients diagnosed with a prior myocardial infarction (MI), ventricular tachycardia (VT) is a life-threatening co-morbidity. Although implantable cardioverter defibrillators (ICDs) have been shown to reduce the risk of sudden death [1], they cannot by themselves, prevent the occurrence of arrhythmias. Recently, catheter ablation of ventricular tachycardia has been emerging as an effective therapy [2], but the optimal target and endpoint of the procedure are still controversial.

The efficacy of radiofrequency catheter ablation (RFCA) for VT in the setting of a structural heart disease was commonly defined by arrhythmia inducibility with programmed electrical stimulation, at the end of the procedure. Abolition of late potential (LP) has recently been proposed to reduce the risk of VT recurrences

and to provide a better follow-up outcome [3]. However, an extensive management of all abnormal local electrical activity within scar tissue requires prolonged procedure time and might lead to greater myocardial damage or adverse events.

We hypothesized that patients with prior-MI showed improved freedom from recurrent VT, if RF current was delivered to the critical channel of the reentry circuit, not to all LPs. This study sought to clarify the optimal procedure end point and the long-term follow-up data on catheter ablation for prior-MI.

2. Material and methods

2.1. Study subjects

This study included 51 consecutive patients (six females, mean age 65.5 ± 11.4 years) undergoing RFCA of VT due to a prior MI (prior MIVT), between September 2004 and August 2012. The locations of the previous MIs were the inferior region in 26 patients, anterior in 22, and both in 3 patients. The mean left

* Correspondence to: Department of Cardiology, Kokura Memorial Hospital, 3-2-1 Asano Kokurakita-ku, Kitakyushu 802-8555, Fukuoka, Japan.
E-mail address: masato_f0728@yahoo.co.jp (M. Fukunaga).

ventricular ejection fraction (LVEF) was $33.2 \pm 9.5\%$. Thirty-five patients had an ICD and seven had a cardiac resynchronization therapy with defibrillator (CRT-D). Twenty-six of the 51 patients had received long-term (> 2 months) therapy with amiodarone, and three had been treated with sotalol. Electrical storms (ESs) had occurred in 12 patients. An ES was defined as the occurrence of three episodes of VT separated by 5 min during a 24-h period, each resulting in an appropriate shock by the ICD [4]. Written informed consent was obtained before the procedure, from all of the patients. This study was approved by the ethical committee of Kokura Memorial Hospital.

2.2. Electrophysiological study

The procedure was performed under local anesthesia. A quadripolar catheter was placed via the femoral vein into the right ventricular apex. Patients underwent a routine electrophysiological evaluation before and after the VT ablation. The stimulation protocol recommended to induce VTs with up to two extra stimuli during pacing, at two cycle lengths (400 ms and 500 ms), from two right ventricular sites (right ventricular apex and right ventricular outflow tract). Isoproterenol infusion was titrated to increase the sinus rate by 25% [5]. The endpoint of the stimulation was the final stimulus reaching the refractory period, or initiation of sustained VT or ventricular fibrillation (VF).

2.3. Mapping and ablation

A conventional computerized electrophysiological system and CARTO (Biosense Webster, Diamond Bar, CA, USA) electro-anatomical mapping system were used in all cases. Mapping and ablation were performed using 7F steerable catheters with either a conventional 8 mm tip (Ablaze; Japan Lifeline, Tokyo, Japan or Navistar; Biosense-Webster, Diamond Bar, CA, USA) or a 3.5 mm irrigated tip electrode (ThermoCool; Biosense-Webster, Diamond Bar, CA). The standard access to the left ventricle was retrograde, across the aortic valve. In some patients, an ante-grade trans-septal access was used, because of severe atherosclerosis of the aorta or peripheral arteries.

The main target of our ablation was the isthmus of all the induced, sustained VTs. RF applications targeted the putative channels within the low-voltage area, from the identified isthmus to the exit of the circuit. When the induced VTs were hemodynamically stable, VT mapping and ablation were performed with conventional entrainment pacing at sites with diastolic potentials, according to the methods previously described by Stevenson et al [6]. When the induced VTs were hemodynamically unstable, mapping and ablation was done during sinus rhythm, with long pacing latency from the QRS onset, at sites with delayed potentials identical to the induced VT morphology [7]. The conventional RF applications were delivered using a temperature-controlled mode (maximum 60 °C; maximum 180 s; 30–50 W; Stockert; Biosense-Webster or CABL-IT; Japan Lifeline). For the irrigated tip catheters, RF applications at 30–50 W were applied with a temperature limit of 43 °C. For systemic anticoagulation, repeat bolus injections of heparin based on activated clotting time measurements were given (target value > 250 s).

Procedural success was defined as the achievement of the non-inducibility of the induced VTs before the procedure, but allowing for the induction of a non-clinical, hemodynamically unstable VT or VF. Recurrence was defined by documentation of any sustained VT, VF or ICD shocks. Follow-up was provided at least every 6 months, by ICD check, examination, or contacts by telephone.

2.4. Statistical analysis

All measured data are reported as the mean \pm SD. In all cases, the statistics were calculated using non-parametric tests (Mann-Whitney, x2) and the Fisher's exact method, because the data set was small. A two-tailed probability of $p < 0.05$ was regarded as significant. The P-values were individually interpreted as exploratory. Statistical analysis was performed using JMP[®] 10.0.0 software (SAS Institute Inc., Cary, NC, USA).

3. Results

During the initial electrophysiological study, at least one monomorphic VT was induced in 49 (96%) of the 51 patients. VT mapping was obtained in 27 patients (53%), while substrate mapping was obtained in 24 patients, because of hemodynamic stability or the non-inducibility of a sustained VT. Procedural success was obtained in 49 of the 51 patients (96%). Forty-two patients (82%) received an ICD implant after ablation and 35 patients (69%) were administered amiodarone. At the end of the procedure, all VTs were non-inducible in 30 patients, non-clinical hemodynamically unstable VT was inducible in 19 patients, and clinical VT was still inducible in 2 patients. According to the inducibility, the patients were divided into two groups (Figs. 1 and 2).

The patient characteristics and electrophysiological data are listed in Tables 1 and 2. There were no significant differences between the two groups regarding age, gender, location of infarction, history of ES, and LVEF (34.3% vs. 31.7%; $P=0.34$). The average number of induced VTs before the ablation was significantly larger in the induced group (1.8 ± 1.2 vs. 2.9 ± 1.9 ; $P=0.02$). The procedure time and the number of RF applications were also significantly larger in the induced group. The identification of the channel during VT mapping was more likely in the non-inducible result group (50% vs. 19%; $P=0.04$). The location and electrogram amplitude of the critical channel is shown in Table 3. Majority of the critical channels were located in the scar area, with a signal amplitude < 0.5 mV on electrogram. No mitral isthmus VT was found in this study.

Table 1
Clinical Characteristics of the Study Patients

	Total (n=51)	Non-inducible (n=30)	Inducible (n=21)	p Value
Age, mean \pm SD	69.5 \pm 11.5	69.5 \pm 11.1	69.7 \pm 12.2	0.94
Male	45 (88%)	27 (90%)	18 (86%)	0.68
Ejection fraction (%), mean \pm SD	33.2 \pm 9.5	34.3 \pm 10.3	31.7 \pm 8.0	0.34
Previous ICD^a (%)	16 (31%)	9 (33%)	7 (33%)	1.0
Localization of infarction				
Anterior (%)	22 (43%)	10 (33%)	12 (57%)	
Inferior (%)	26 (51%)	18 (60%)	8 (38%)	
Anterior and Inferior (%)	3 (6%)	2 (7%)	1 (5%)	
History of ES^b	12 (24%)	9 (33%)	3 (14%)	0.31
Use of amiodarone (%)	26 (51%)	13 (43%)	14 (67%)	0.15
Use of sotalol (%)	3 (6%)	3 (10%)	0	0.25
Use of β blocker (%)	36 (71%)	24 (80%)	14 (67%)	0.34
Use of ACE-I^c or ARB^d (%)	35 (69%)	22 (73%)	15 (71%)	0.71

Data are presented as the mean \pm SD or n (%).

^a ICD = implanted cardioverter defibrillator;

^b ES = electrical storm;

^c ACEI = angiotensin-converting enzyme inhibitor;

^d ARB = angiotensin receptor blocker.

Table 2
Procedural data.

	Total (n=51)	Non-inducible (n=30)	Inducible (n=21)	p Value
Cycle length of induced VT (ms)	388 ± 84	395 ± 85	352 ± 67	0.08
Induced VTs, n/patient	2.2 ± 1.6	1.8 ± 1.2	2.9 ± 1.9	0.02
VT ^a mapping (%)	27 (53%)	18 (60%)	9 (43%)	0.27
Identification of the channel in VT mapping (%)	19 (37%)	15 (50%)	4 (19%)	0.04
Mapping point, n	151 ± 50	143 ± 49	163 ± 50	0.14
Size of low voltage area (cm ²)	36.2 ± 21.5	36.9 ± 23.2	35.3 ± 19.5	0.8
Fluoroscopy time, min	29 ± 14	27 ± 13	32 ± 16	0.24
Procedure time, min	193 ± 45	177 ± 40	217 ± 42	0.001
RF lesion, n	18 ± 11	16 ± 9	22 ± 12	0.03
Irrigated RF ^b catheter (%)	27 (53%)	16 (53%)	11 (52%)	1.0
Follow-up time after hospital discharge (months)	41 ± 29	40 ± 26	42 ± 34	0.84
Total number of patients with ICD ^c after ablation (%)	42 (82%)	23 (77%)	19 (90%)	0.27
Amiodarone after ablation (%)	35 (69%)	18 (69%)	17 (81%)	0.14

Data are presented as the mean ± SD or n (%).

^a VT=ventricular tachycardia;

^b RF=radiofrequency;

^c ICD=implanted cardioverter defibrillator.

Table 3
Location and local electrogram amplitude of the critical channel.

	Total (n=51)	Anterior (n=22)	Inferior (n=26)	Anterior and inferior (n=3)
Amplitude of the critical channel				
< 0.1 mV	2	0	2	0
0.1–0.5 mV	14	5	8	1
0.5–1.5 mV	3	3	0	0
Mean value of the amplitude (mV)	0.30	0.38	0.23	0.41

During a mean of 41 ± 29 months of follow-up, freedom from VT or VF was observed more frequently in the non-inducible group (24 of 30 (75%)) than in the inducible group (9 of 21 (43%), $P=0.03$). The estimated cumulative freedom from VT or VF was 88%, 83%, 75%, and 55% at the 1-, 2-, 3-, and 5-year follow-up visits (96%, 88%, 83%, and 69% in the non-inducible result group and 75%, 75%, 64%, and 39% in the inducible result group, respectively). A Kaplan–Meier curve of the freedom from VT or VF is shown in Fig. 3. The identification of the channel during VT mapping tended to associate with freedom from the recurrence, although the difference was not statistically significant ($P=0.2$) (Fig. 4).

Fourteen patients (27%) died during the follow-up period due to the following reasons: sudden death (4), infection (3), carcinoma (2), renal failure (1), senility (1), and unknown, but not sudden death (3). There were no significant differences between the two groups in regards to all-cause mortality (Fig. 5). Sudden death occurred in two patients in the non-inducible group and two in the inducible group. An ICD was implanted in all four patients, but ICD activities were logged in only one patient. One patient was suspected to have died due to heart failure (patient was frequently hospitalized) and the other two patients died due to unknown causes. In terms of complications associated with procedure, one stroke occurred within 24 hours after the procedure, in a patient with an ES.

4. Discussion

4.1. Main findings

The main findings of this study were as follows: (1) the catheter ablation targeting the isthmus of prior-MIVT showed a satisfactory follow-up result; (2) the recurrence rate in the non-

inducible group was significantly lower than that in the inducible group, and (3) approximately one quarter of the patients died after the RFCA during 41 months of follow-up, mostly due to non-cardiac causes.

4.2. An optimal end point of catheter ablation of a prior-MI

A better outcome was previously reported for patients in whom a critical isthmus of the VT could be identified, than in those in whom an isthmus could not be characterized [8]. Conventional electrophysiological maneuvers such as entrainment mapping and VT-mapping, facilitate an understanding of the circuit in VT. For the patients who hemodynamically collapsed during VT, electro-anatomical mapping systems enabled us to perform substrate mapping during sinus rhythm. Volkmer et al. reported no significant differences between VT-mapping or substrate mapping in terms of freedom from VT recurrence [9]. These two different strategies do not reduce the importance of aiming for a critical isthmus, but mean that careful mapping of the infarct area or pacing maneuvers are as effective in identifying the critical channels as VT-mapping. In terms of an endpoint, targeting LP abolition seems to be effective and simple [2], but it tends to require more RF applications and has the potential risk of partial damage to the critical isthmus, resulting in edema formation in the surrounding area. We have a dilemma regarding how extensively the low voltage area should be ablated.

Recently, Pauriah et al. attempted to determine the possibility of using RFCA as the first-line treatment for prior-MIVT. They showed the effects of a stepwise algorithm based on acute success, repeat electrophysiological studies, and recurrence of VT [10]. A stepwise algorithm is attractive, but it is still difficult to decide the endpoint during the procedure. Acute success is typically defined by the non-inducibility with programmed electrical stimulation, at the end of the ablation. In the setting of patients with electrical storms, programmed stimulation is a reasonable marker for prevention of electrical storm recurrence [11]. In a clinical setting, a variety of conditions affect the assessment of a successful procedure such as the EF, low voltage area, inability to document the clinical VT morphologies, hemodynamically stable VT, and difficulty in the induction of VT before the procedure.

In this study, we assessed the impact of the catheter ablation for the patients with prior-MI. In order to avoid extensive ablation, a modest stimulation protocol with up to two extra stimuli was applied to induce VT. Our goal was not to abolish all delayed potentials, but to target the isthmus, which formed a circuit of

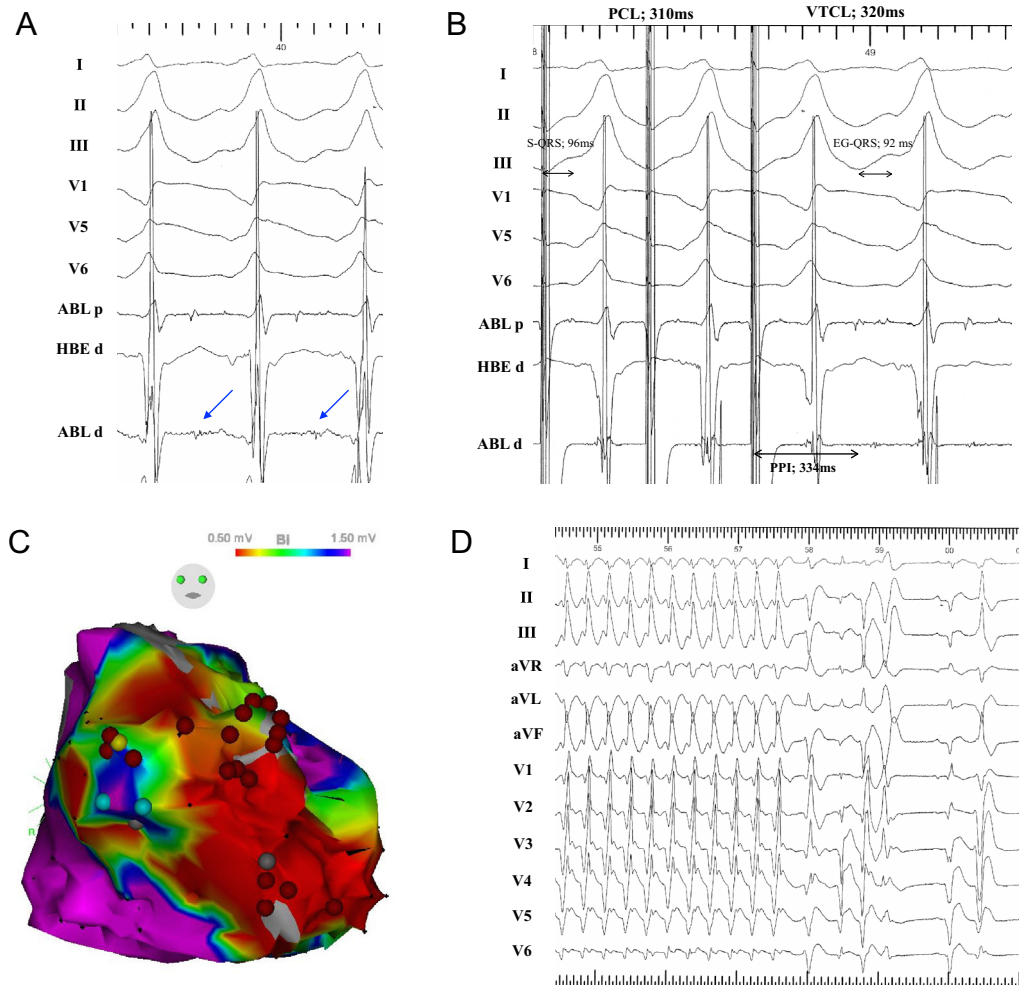


Fig. 1. A representative case for non-inducible group. (A) The mid-diastolic potentials (arrows) recorded during VT. (B) Entrainment pacing at that point showing the exit to the central isthmus of the circuit. (C) The bipolar endocardial voltage map of the case. Red tags show ablation points. (D) The VT terminated 3 seconds after RF application. VT=ventricular tachycardia; EG-QRS=electrogram-QRS interval; PCL=pacing cycle length; PPI= post pacing interval; S-QRS=stimulus-QRS interval; VTCL=VT cycle length. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

sustained VTs. In our study, the identification of the channel during VT mapping was not associated with a better prognosis, but the sample size seemed to be underpowered statistically in order to show a definite benefit. Precise mapping targeting the isthmus could be a way to improve the long-term success. The inducibility at the end of the procedure is still a powerful predictor that helps evaluate VT recurrence and fragility in a patient. According to previous studies, most of the programmed stimulation protocols included up to three or even four extra stimuli [12]. If a more difficult end point were set, it would require more procedure time and RF applications. Our procedure time (193 ± 45 min) and RF lesions (18 ± 11 times) were acceptable for minimizing any unexpected complications. Our ablation strategy, targeting the critical isthmus and exit of the VT circuit, benefits from understanding the entire picture of the VT circuit and requires the provider to become proficient in a variety of new and classical electrophysiological maneuvers in order to analyze the local potential.

Compared to the study with the largest number of patients with prior-MIVT [13], our long-term data provided similar results with regards to freedom from VT recurrence. In that study, VT was inducible before the procedure in 93.8% of the patients. With a median of 634 days per patient, the group whose VT was rendered non-inducible had significantly greater freedom from VT recurrences when compared with the group in whom the VT remained

inducible (61.3% vs. 45.4%, respectively; $p < 0.001$). Non-inducibility was independently also associated with lower mortality (adjusted hazard ratio: 0.65; 95% confidence interval: 0.53–0.79; $p < 0.001$). In our study, although the programmed stimulation protocol was modest, inducibility was almost the same at the baseline (96%). Freedom from VT or VF recurrence was almost similar (55% in the non-inducible group vs. 39% in the inducible group, at the 5-year follow-up visits). It is very important to confirm the effect of catheter ablation with inducibility at the end of the procedure, but it is still necessary to improve the long-term success among patients in whom some VTs remain inducible or VT is non-inducible before ablation. In our study, VTs were not inducible at the baseline in 2 patients with an ICD; a 12-lead ECG of VT was obtained previously due to the slower VT cycle length than the ICD setting in one patient, and no clinically relevant ECG was obtained in the other patient. Information about clinical VTs is a key for a better procedure. Although patients with an ICD sometimes have limited information about VT, we should make efforts to get as many clinical 12-lead ECGs of VT as possible before the procedure.

With regard to mortality, our study showed no difference between the two groups. This could be explained by the higher rate of non-cardiac death and the high usage of amiodarone after ablation.

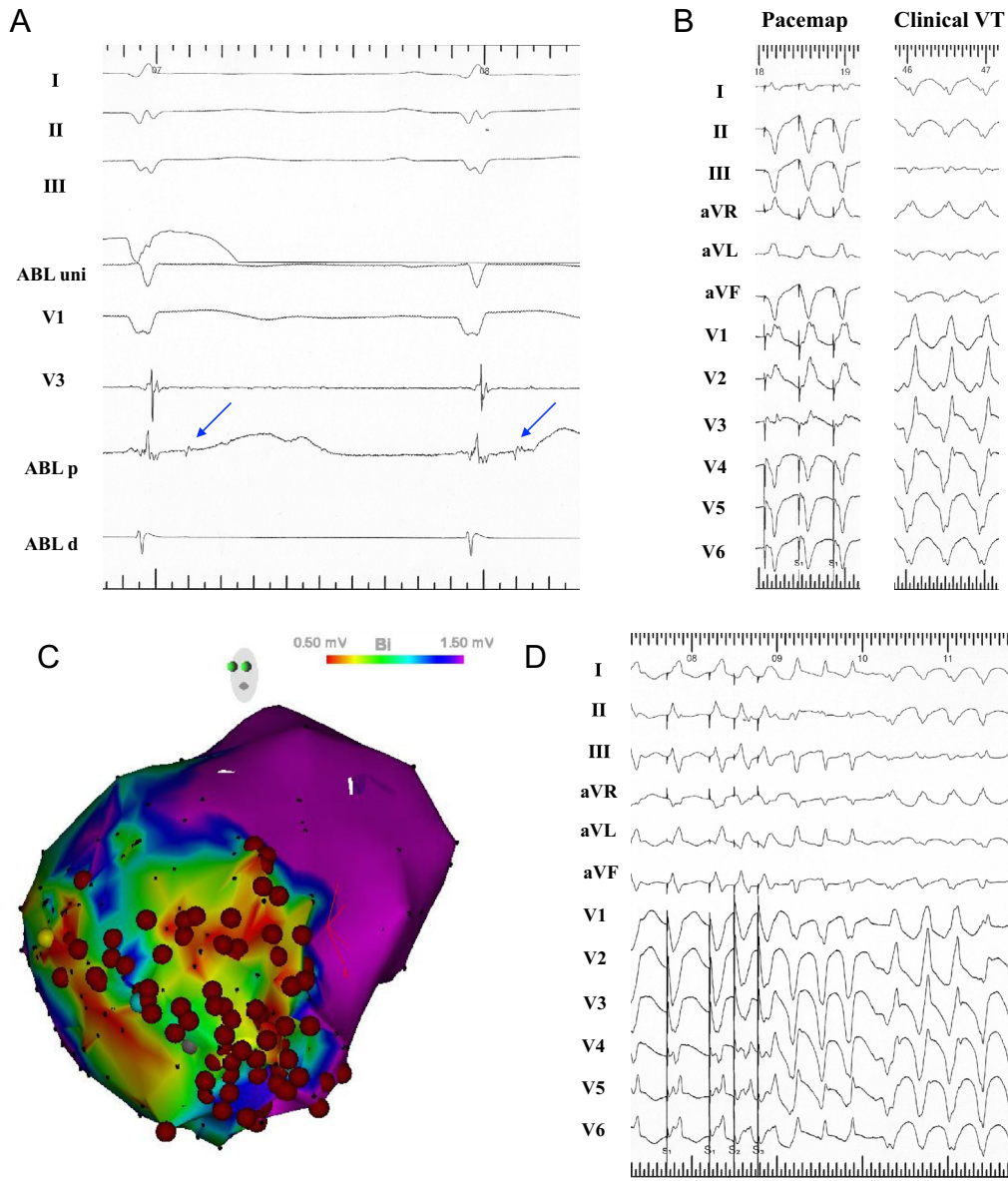


Fig. 2. A representative case for the inducible group. (A) Delayed potentials (arrows) recorded during sinus rhythm. (B) Surface ECG during VT and a pace map. (C) The bipolar endocardial voltage map of the case. Red tags show the ablation points. (D) Sustained VT still inducible at the end of the procedure.

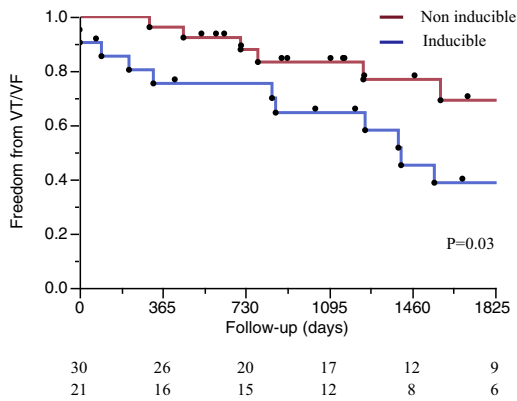


Fig. 3. The Kaplan–Meier curve shows freedom from VT or VF recurrence, for patients with a non-inducible result and those with an inducible result at the end of the procedure. There is a statistically significant difference between the two groups (log-rank test, $P=0.03$).

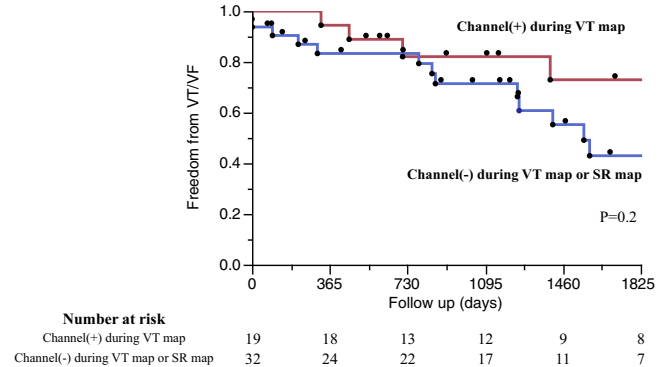


Fig. 4. The Kaplan–Meier curve shows freedom from VT or VF recurrence between patients whose critical channel was identified during VT mapping and patients whose critical channel was not identified during VT mapping or ablation performed during SR. Freedom from recurrence and identification of the critical channel seemed to be associated, although the difference was not statistically significant (log-rank test, $P=0.2$).

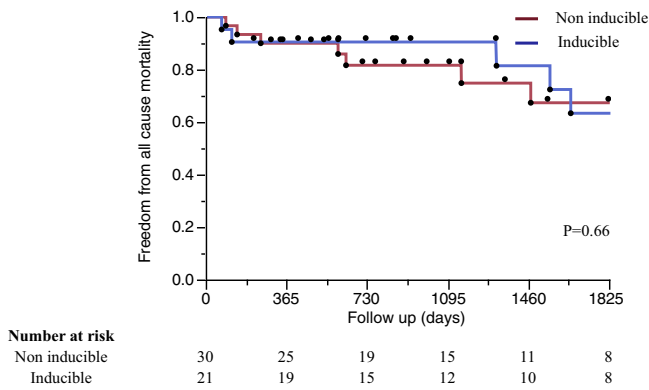


Fig. 5. The Kaplan–Meier curve shows freedom from all-cause mortality among patients with a non-inducible result and those with an inducible result at the end of the procedure. There is no statistically significant difference between the two groups (log-rank test, $P=0.66$).

4.3. Limitations

The first limitation is that this was an observational study and not a randomized controlled study. ICDs were not implanted in all patients because of the patient's preference or a preserved EF. All sudden deaths in this study occurred in patients with an ICD, but two patients in the inducible group died due to unknown causes.

Second, an epicardial approach was attempted in four patients in the second procedure. In this study, only the first procedure was taken into consideration. Epicardial arrhythmogenic substrate may have existed, but it is usually not so associated with MIVT.

Third, the study size was too small to allow for division into subgroups. A greater number of patients will be needed for further study, and our strategy needs to be evaluated.

5. Conclusions

Catheter ablation in patients with prior MI, targeting not all of the delayed potentials but the isthmus, showed a satisfactory follow-up result. Subsequent non-inducibility showed an even higher rate of freedom from VT or VF. The incidence of the freedom from VT or VF in the non-inducible result group was 69% during a 5-year follow-up.

Conflict of interest

All authors declare no conflict of interest related to this study.

Grant

None.

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