Electrocardiographic Characteristics of the Variants of Idiopathic Left Ventricular Outflow Tract Ventricular Tachyarrhythmias

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Left Ventricular Outflow Tract VTs. ***Background:*** **Despite similar QRS morphology, idiopathic repetitive monomorphic ventricular tachyarrhythmias (VTs) of left ventricular outflow tract (LVOT) are known to have the variants of different adjacent origins, including the aorto-mitral continuity (AMC), anterior site around the mitral annulus (MA), aortic sinus cusps (ASC), and epicardium. However, the electrocardiographic characteristics of those variants previously have not been evaluated fully.**

Methods and Results: **Based on the mapping site and successful ablation in 45 consecutive patients with LVOT-VTs, we classified them into VTs of AMC (n = 3), MA (n = 8), ASC (n = 32), and epicardial (n = 2) origins. In all patients, we performed activation mapping and an electrocardiographic analysis. All AMC-VTs patients had monophasic R waves in almost all the precordial leads, while those with anterior MA-VTs had an Rs pattern in some precordial leads except for lead V6, and those with ASC-VTs had a variable transitional zone in leads V1–4. There was no S wave in lead V6 in any group except for one patient with anterior MA-VTs. The intrinsicoid deflection time in the AMC-VTs patients and anterior MA-VTs patients was significantly greater than in those with ASC-VTs ($P < 0.05$). There was no significant difference in the R-wave amplitude in the inferior leads among the groups. Successful radiofrequency catheter ablation (RFCA) was achieved in all patients except for in those with epicardial origin VT.**

Conclusions: **Despite many morphological similarities, the LVOT-VTs originating from the AMC, anterior MA and ASC could be identified by our proposed electrocardiographic characteristics in order to safely perform RFCA.** *(J Cardiovasc Electrophysiol, Vol. 19, pp. 495-501, May 2008.)*

idiopathic ventricular tachyarrhythmias, left ventricular outflow tract, catheter ablation

Introduction

Radiofrequency catheter ablation (RFCA) has been established as an effective and safe nonpharmacological therapy for arrhythmias. The indication for RFCA has been rapidly widened, from supraventricular tachycardia a decade ago to ventricular tachyarrhythmias (VTs) with underlying heart disease[1] and atrial fibrillation[2] in recent days. Regarding the RFCA for VTs, most cases of idiopathic repetitive monomorphic ventricular tachycardia and symptomatic monomorphic ventricular premature contractions (VPCs) are known to originate from the right ventricular outflow tract (RVOT), and RFCA has been widely accepted as a curative therapy for RVOT-VTs due to the high success rate.[3,4] In contrast, some cases of VTs also originate from the left ventricular outflow tract (LVOT),[5-7] and it is important to safely perform the RFCA for those LVOT-VTs due to the critically important anatomical origin. Various origins of LVOT-VTs are known to exist within a very close anatomical location, including the aortomitral continuity (AMC), anterior site around the mitral annulus (MA), aortic sinus cusps (ASC), superior basal septum and epicardium.[5-10] It has been difficult to differentiate those various origins of the LVOT-VTs because they all exhibit similar QRS morphologies, including a right bundle branch block (RBBB) morphology in lead V1 or atypical left bundle branch block (LBBB) morphology associated with an early precordial transition in lead V2.[11] Specifically, VTs originating from the AMC have overlapped with some from anterior sites around the MA and ASC because the AMC is located adjacent to both the aortic and mitral annuli. Therefore, it is important to differentiate the electrocardiographic characteristics among the various

This work was supported in part by the grant-in-aid from the Japanese Ministry of Education, Culture, Sports, Science, and Technology, Tokyo, Japan (No. 18590759).

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Manuscript received 26 May 2007; Revised manuscript received 7 November 2007; Accepted for publication 9 November 2007.

doi: 10.1111/j.1540-8167.2007.01085.x

LVOT-VT types in order to safely perform RFCA. This study was thus designed to examine and compare the electrocardiographic characteristics among those variants of LVOT-VT types.

Methods

Study Population

Forty-five consecutive patients (24 men and 21 women; mean age: 58 ± 17 years) with symptomatic repetitive monomorphic ventricular tachycardia and frequent monomorphic VPCs originating from the LVOT were examined in a retrospective review. All patients gave their documented informed consent. RFCA therapy for their left ventricular VTs was performed between February 1998 and March 2006. All patients had no structural heart disease, such as coronary artery, myocardial, or valvular heart disease, as assessed by the chest X-ray, baseline ECG, echocardiography, and coronary angiography.

EP Study and Ablation Procedure

All antiarrhythmic drugs were discontinued at least five half-lives before the electrophysiological (EP) study. Pace and activation mapping of the repetitive monomorphic ventricular tachycardias or frequent monomorphic VPCs were performed with a CardioLab (GE Prucka, Houston, TX, USA) standard recording system using the roving catheter technique as previously described.[9] If no repetitive monomorphic ventricular tachycardias or VPCs occurred spontaneously and were not induced during the baseline state, an intravenous infusion of isoproterenol (0.5–4 μg/min) was used to induce the clinical ventricular tachycardia or VPCs. Bipolar intracardiac electrograms were filtered with a band-pass of 30–500 Hz and the unipolar intracardiac electrograms from the ablation catheter were filtered with a band-pass of 0.5–500 Hz. Bipolar pace mapping was performed during sinus rhythm at an output just greater than the diastolic threshold from the distal electrode pair. We first mapped the RVOT area and pulmonary artery, followed by careful mapping of the LVOT area and MA via the retrograde aortic approach, and ASC, if necessary.

RF energy was delivered using a 7F quadripolar catheter with a deflectable 4 mm tip (EPT5031TL: EP Technologies Inc., San Jose, CA, USA) and temperature control system (EPT1000; EP Technologies Inc.) with a temperature setting of 55°C and a maximum power of 50 Watts during 60 second energy deliveries. RF energy was never delivered more than three times in any patients with ASC-VTs.[9] The target site for the ablation was determined primarily by a perfect (12/12) or near-perfect (10-11/12) pace map, with the earliest ventricular electrogram preceding the onset of the QRS during VTs. Although the pacing threshold was >8 V during pace mapping from a coronary cusp, pace mapping was performed successfully in all cases.[9] Successful RFCA sites were considered as the sites of origin of the VTs.

Definition of the Location of the AMC and Anterior Sites Around the MA

The position of the ablation catheter at the MA was verified by fluoroscopy, and confirmed by the endocardial ECG in which the atrial/ventricular ratio of the amplitude was less than one. We defined an AMC site as one where the catheter tip was located at about 11 o'clock around the MA and anterior site as that from the AMC site to 1 o'clock around the MA in the right and left anterior oblique fluoroscopic views.

12-Lead ECG Analysis

The 12-lead ECG was analyzed based on the following four parameters: (1) QRS morphology, (2) presence or absence of an S wave in the precordial leads, (3) amplitude of the R wave in the inferior leads, and (4) intrinsicoid deflection time (IDT).[12] The IDT was defined as the interval measured from the earliest ventricular activation to the peak of the R wave in lead V2. All measurements were analyzed in a blinded fashion by two electrophysiologists using digitized tracings with calipers allowing a 1 ms resolution at a screen speed of 100 mm/sec and with the signals amplified to 10 mm/mV. We used the mean values of those measurements as the data. If the interobserver difference was more than 5 ms, the final decision was made by a joint meeting of the observers.

Statistical Analysis

The continuous data are expressed as the mean ± SD. The mean values were compared using the Student's unpaired *t*-test. Data among the three groups were analyzed by the Kruskal–Wallis test and statistical significance of differences among the three groups was further examined by the Steel-Dwass test for multiple comparisons. A value of $P < 0.05$ was considered to be statistically significant.

Results

Sites of Origin of the LVOT-VTs

The AMC (left fibrous trigone), which is an anatomical marker for the LVOT, consists of the aortic annulus and anterior site around the MA. Figure 1 shows the endoscopic view of the LVOT from the LV apex (A) and the view from "above" that concentrates on the aortic and mitral annuli (B) reconstructed by multi-dimensional CT. The images indicated that the AMC (the left fibrous trigone) was anatomically located very close to the anterior MA site and ASC.

Based on the successful ablation site in the 45 patients with LVOT-VTs, we identified the following; ASC-VTs in 32 patients (71%) (Fig. 2), anterior MA-VTs in eight (18%) (Fig. 3) and AMC-VTs in three (7%) (Fig. 4). A conventional endocardial or coronary cusp approach was not useful for eliminating epicardial origin VTs in 2 (4%) (Epi-VTs). Among the 32 patients with ASC-VTs, the origin was the left ASC in 30 patients and the right ASC in two.

Among the clinical characteristics of the patients with LVOT-VTs, nonsustained repetitive monomorphic ventricular tachycardias or frequent monomorphic VPCs were observed in 35 patients (78%), and sustained repetitive monomorphic ventricular tachycardias in 10 (22%) (anterior MA-VTs in one, left ASC-VTs in seven, and Epi-VTs in two). All patients with LVOT-VTs were symptomatic and suffered from recurrent palpitation episodes without near syncope or syncope.

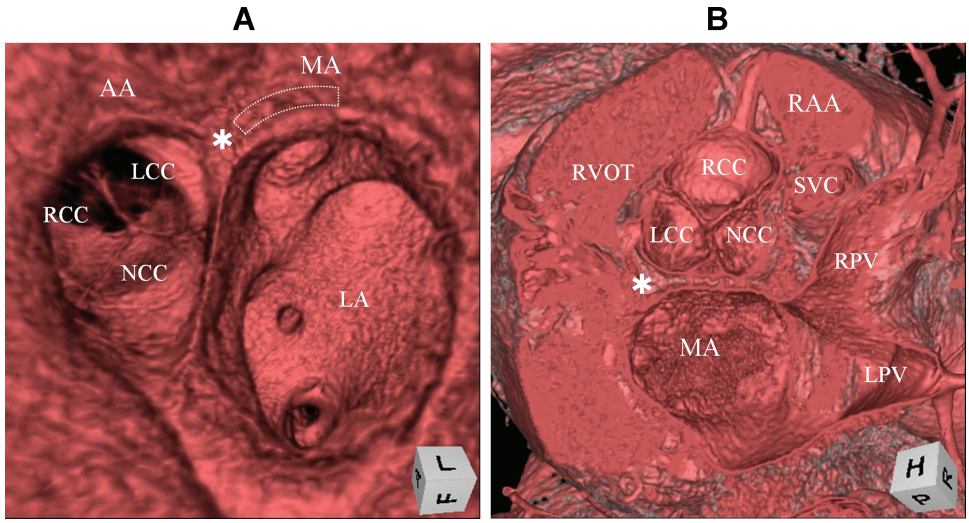

Figure 1. *A multidimensional CT (MDCT) was performed to define the anatomical position of the left ventricular outflow tract (LVOT). The figures show the endoscopic view of the LVOT from the LV apex (A) and the view from "above" that concentrates on the aortic and mitral annuli (B) reconstructed by multidimensional CT. The left fibrous trigone (asterisk) is represented in the limited area between the ridges of the aortic and mitral annuli. The aortic leaflet of the mitral valve cannot be seen in this MDCT. Note that there is no septal myocardium in the region beneath the left fibrous trigone. The dotted line represents the area of the anterior site of the mitral annulus. LCC = left coronary cusp; RCC = right coronary cusp; NCC = non coronary cusp; RPV = right pulmonary vein; LPV = left pulmonary vein; AA = aortic annulus; MA = mitral annulus; LA = left atrium; RAA = right atrial appendage; RVOT = right ventricular outflow tract; SVC = superior vena cava.*

EP Study and RFCA of LVOT-VTs

In 35 out of the 45 patients (78%), nonsustained repetitive monomorphic ventricular tachycardias or frequent monomorphic VPCs occurred spontaneously or were induced by an intravenous isoproterenol (0.5 to 4 μg/min), but not by programmed ventricular stimulation. In all the repetitive monomorphic VTs except for Epi-VTs, pace mapping was useful for determining the RFCA sites. Successful RFCA was achieved at a perfect (12/12) or near-perfect (10-11/12) pace match site. The earliest ventricular electrogram (V) at the successful ablation site preceded the onset of the QRS by 37 $\pm$ 15 msec. A low-amplitude presystolic potential (prepotential) was frequently observed during the VTs at the successful ablation sites (34/45, 76%). RFCA successfully eliminated the repetitive monomorphic VTs in all patients except the patients with Epi-VTs. The previous criteria were applied to distinguish these Epi-VTs from endocardial origin VTs.[13] The Epi-VTs had an atypical left bundle branch block morphology with an inferior axis, precordial R-wave transition in V2 and no S wave in lead V6. However, in the Epi-VTs, no good pace map with an endocardial ventricular activation earlier than that recorded in the anterior interventricular vein (AIV) was achieved. A near-perfect pace map with the earliest ventricular activation was obtained at the junction between the great cardiac vein and AIV. The position of the ablation catheter was verified by bilateral fluoroscopic imaging and an endocardial atrial/ventricular ratio of the amplitude of less than one was observed at the successful ablation site in the AMC-VTs and anterior MA-VTs. In the ASC-VTs, coronary angiography was performed before RFCA to assure that there was a distance of more than 10 mm between the ablation catheter and ostium of the left main coronary artery.[9] No complications from the RFCA were noted, but five patients (four patients with ASC-VTs and one with anterior MA-VTs) had an early recurrence of VTs within a month after the therapy during the follow-up period of 12 months. Additional session was not performed because the patients with recurred VT were asymptomatic.

The 12-Lead ECG Characteristics of the AMC-VTs

The early transitional zone was located in leads V1-2 in the AMC-VTs and anterior MA-VTs. All patients with AMC-VTs exhibited monophasic R waves without S waves in almost all the precordial leads (94%), while those with anterior MA-VTs had a morphology with an S wave (like an Rs or RS pattern) in many of the precordial leads (65%) other than lead V6 (Table 1). The patients with ASC-VTs had a variable transitional zone in leads V1–4 (V1:28%, V2:35%, V3:31%, V4:6%) and two patients had monophasic R waves in all precordial leads. There were no S waves in lead V6 in any of the groups except one patient with anterior MA-VTs. It is conceivable that the variation in the range of fibrous tissue in the left fibrous trigone and cardiac anatomical location contribute to this mismatch.

The QRS duration (ms) in the patients with AMCs and anterior MA-VTs was significantly greater than that in those with ASC-VTs (180 $\pm$ 20, 176 $\pm$ 15 vs. 146 $\pm$ 18, both $P < 0.05$). The IDT (ms) in the patients with AMC-VTs and anterior MA-VTs was also significantly greater than that in those with ASC-VTs (100 $\pm$ 20, 93 $\pm$ 9 vs. 74 $\pm$ 16, both $P < 0.05$). When comparing anterior MA-VTs and ASC-VTs, an IDT of $\geq$ 85 ms identified anterior MA-VTs with a 75% sensitivity and 83% specificity. However, there was no significant difference in the QRS duration or IDT between the patients with AMC-VTs and those with anterior MA-VTs. In addition, there was no significant difference in the R-wave amplitude (mV) in the inferior leads between the AMC-VTs, anterior MA-VTs, and ASC-VTs (in lead II; 2.0 $\pm$ 0.1, 1.9 $\pm$ 0.5, and 2.2 $\pm$ 0.4, N.S.; in lead III; 2.0 $\pm$ 0.2, 2.1 $\pm$ 0.4, and 2.3 $\pm$ 0.5, N.S.; and in lead aVF; 2.0 $\pm$ 0.2, 1.9 $\pm$ 0.7, and 2.3 $\pm$ 0.5, N.S.).

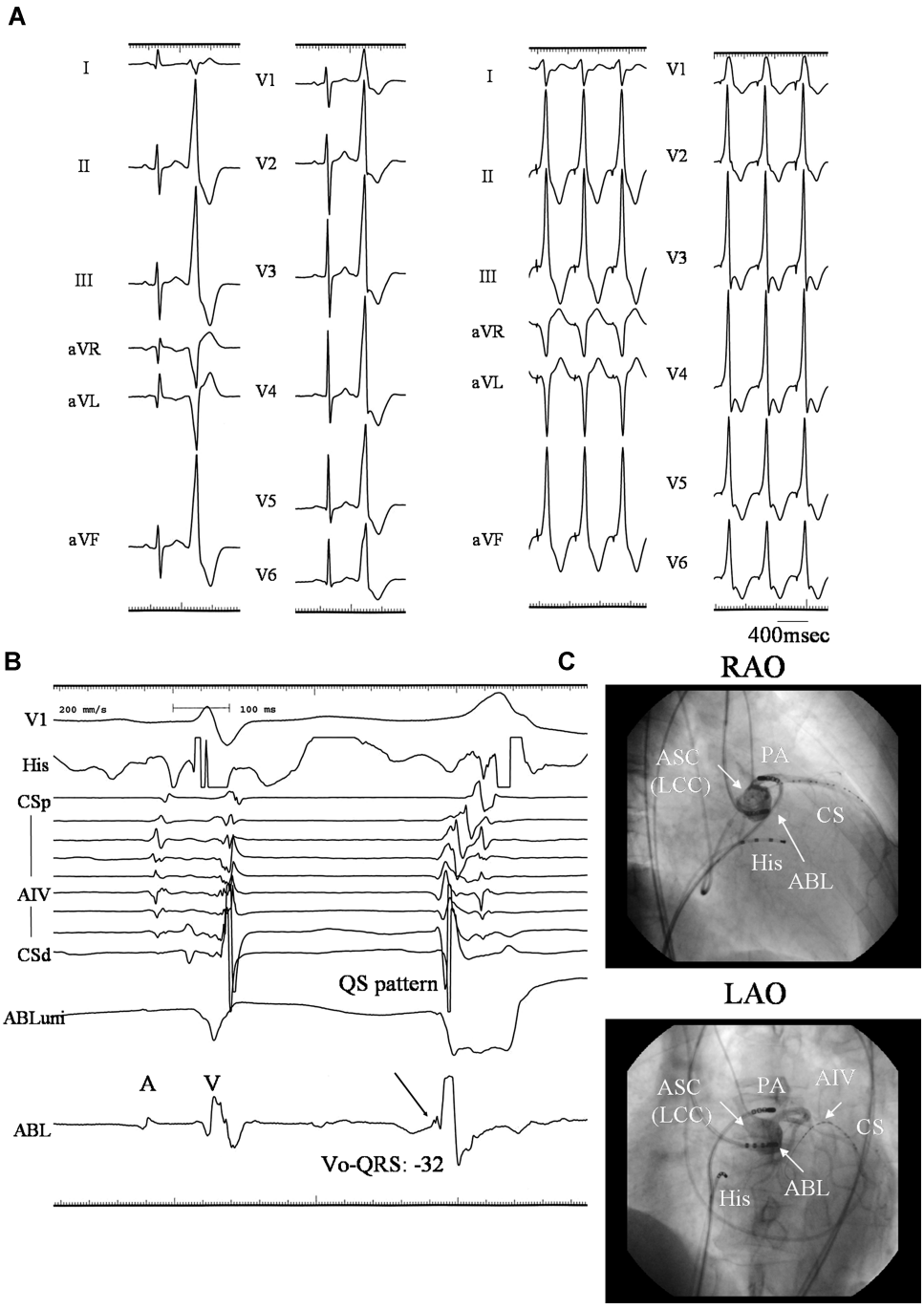

Figure 2. *The ECG recordings obtained during the EP study and catheter position at the successful ablation site in a patient with ASC-VTs. (A) A pace map with a near-perfect match. (B) The earliest activation (prepotential, arrow) preceded the QRS onset (Vo) by 32 ms during a ventricular premature contractions (VPC). The unipolar signal also has a QS morphology with a fast downstroke slope. A = atrial potential; V = ventricular potential. (C) The location of the ablation catheter is in the left coronary sinus cusp. Coronary angiography reveals the left coronary artery and aortic sinus cusps. His = His bundle region; CSp and CSd = proximal to distal sites of the coronary sinus; uni = unipolar electrogram.*

Discussion

Major Findings of the Study

LVOT-VT had various types within a very close anatomical location, including the AMC, anterior site around the MA, ASC, and epicardium. The left fibrous trigone anatomically consisted of the aortic annulus and anterior site around the MA. Despite the existence of origins in a limited area of the LVOT, the specific ECG characteristics of the various types were exhibited, as follows. First, all the patients with AMC-VTs had monophasic R waves in almost all the precordial leads, while those with anterior MA-VTs had a morphology with an S wave in many of the precordial leads other than lead V6. Second, the transitional zone was located in lead V1 in the AMC-VTs and leads V1–2 in the anterior MA-VTs, while those with ASC-VTs had a variable transitional zone in leads V1-4. Third, there were no S waves in lead V6 in any of the groups. Fourth, the IDT in the patients with AMC-VTs and anterior MA-VTs was significantly greater than that in those with ASC-VTs. However, there was no significant difference

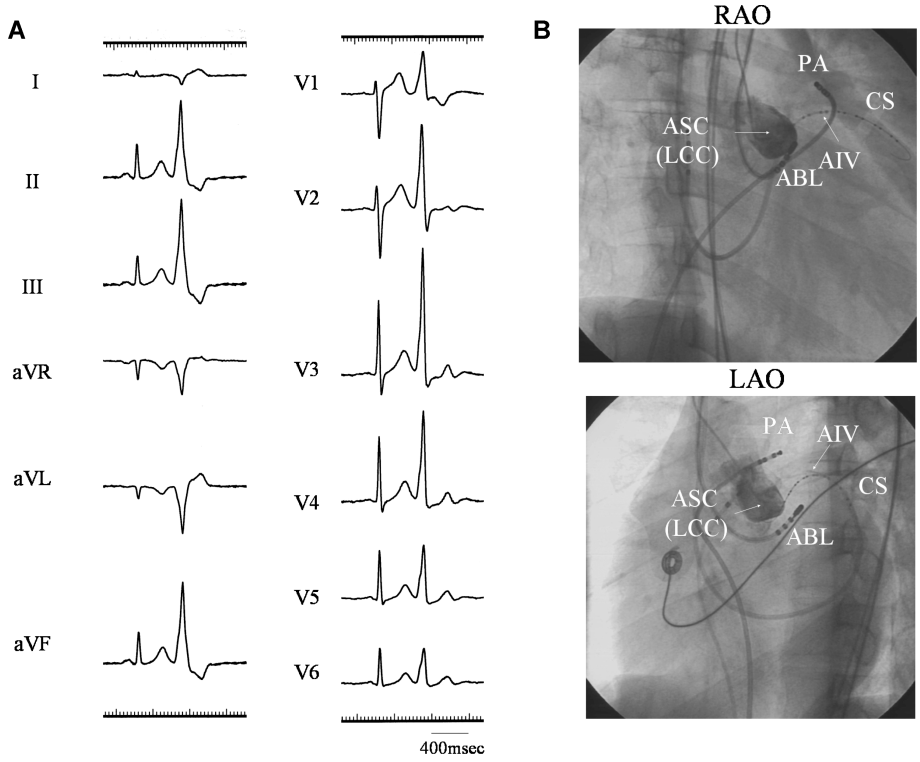

Figure 3. *Twelve-lead ECG and catheter position at the successful ablation site (RAO35° and LAO45°) in a patient with anterior MA-VTs. (A) Twelve-lead ECG of the anterior MAVT. Note that an Rs pattern (morphology with an S wave) in leads V1-3 was exhibited while there were no S waves in lead V6. (B) The location of the ablation catheter is just below the anterior aspect of the mitral annulus. Aortography reveals the aortic sinus cusps. LCC = left coronary cusp; PA = pulmonary artery; CS = coronary sinus; AIV = anterior interventricular vein; ABL = ablation catheter.*

in the IDT between the patients with AMC-VTs and those with anterior MA-VTs. Finally, there was no significant difference in the R-wave amplitude in the inferior leads in any of the groups. All LVOT-VTs except Epi-VTs were successfully treated with RFCA combined with the pace mapping and earliest ventricular electrogram with a prepotential. To the best of our knowledge, this is the first study that defines the ECG characteristics of LVOT-VTs, including AMC-VTs, anterior MA-VTs, and ASC-VTs.

The Aorto-Mitral Continuity

The functional significance of the AMC remains to be fully evaluated. Since the aortic and mitral valves are coupled through the fibrous AMC, the aortic leaflet of the mitral valve can hang between the inflow and outflow tracts of the left ventricle,[14] suggesting that there is no septal myocardium in the region beneath the left fibrous trigone. In addition, a variation in the completeness of the fibrous tissue has been exhibited from each of the fibrous trigones around the valvular annulus.[15] A remnant of the atrioventricular conduction system (dead-end tract) was reported to be close to the AMC.[16] This suggests that musculature aberrations in the fibrous trigone become ectopic foci with a nonreentrant mechanism, such as triggered activity.

AMC-VTs and Anterior MA-VTs of the LVOT-VTs

It was previously reported that the origin of the LVOT-VT was located in either the anterior site of the MA, mediosuperior aspect of the MA (the region of the AMC), superior basal septum (His bundle area), coronary cusp, or epicardium (Fig. 5).[11] In that report, the ECG characteristics of the LVOT-VTs consisted of an RBBB morphology in lead V1 or atypical LBBB morphology associated with an early precordial transition in lead V2. In the present study, however, the AMC-VTs had an RBBB configuration and inferior axis with monophasic R waves in almost all the precordial leads. This suggests that the ventricular activation of the AMC-VTs was directed only anteriorly to the most posterior region of the LVOT corresponding to the AMC (left fibrous trigone).[8] However, a qR morphology in lead V1 in the AMC-VTs, as reported by Dixit *et al.*,[17] was not observed in any of our cases. In addition, there was no significant difference between the groups for the QRS duration and IDT, suggesting that both origins were located deep in the subepicardium, as compared with that for the ASC-VTs. Further, there was no significant difference in the R-wave amplitude in the inferior leads between all the groups, also suggesting that those anatomical locations were very close to each other. In particular, it was difficult to define the difference between AMC-VTs and anterior MA-VTs because their origins might have been distributed along the boundary region of the aortic and mitral annuli (near the left fibrous trigone) to the anterior MA aspect. Therefore, it is possible that some anterior MA-VTs overlapped with the AMC-VTs. However, in the present study, the AMC-VTs exhibited a different morphology in the precordial leads, compared with the anterior MA-VTs.

ASC-VTs of the LVOT-VTs

The ASC-VTs had a broad precordial transition in leads V1–4 and various morphologies in leads I and V1. The QRS duration and IDT in patients with AMC-VTs and anterior MA-VTs were significantly greater, compared with those with ASC-VTs. However, no S waves in lead V6 were observed in any patients with LVOT-VTs. This suggests that the subtype origins were located at a close level of height and that the AMC-VT and anterior MA-VT origins were located deeper in the subepicardium, compared with that of the ASC-VTs. RF applications from the supravalvular region of the aortic valve coronary cusp were ineffective in ablating the valve itself, but ablated the septal myocardium in the region

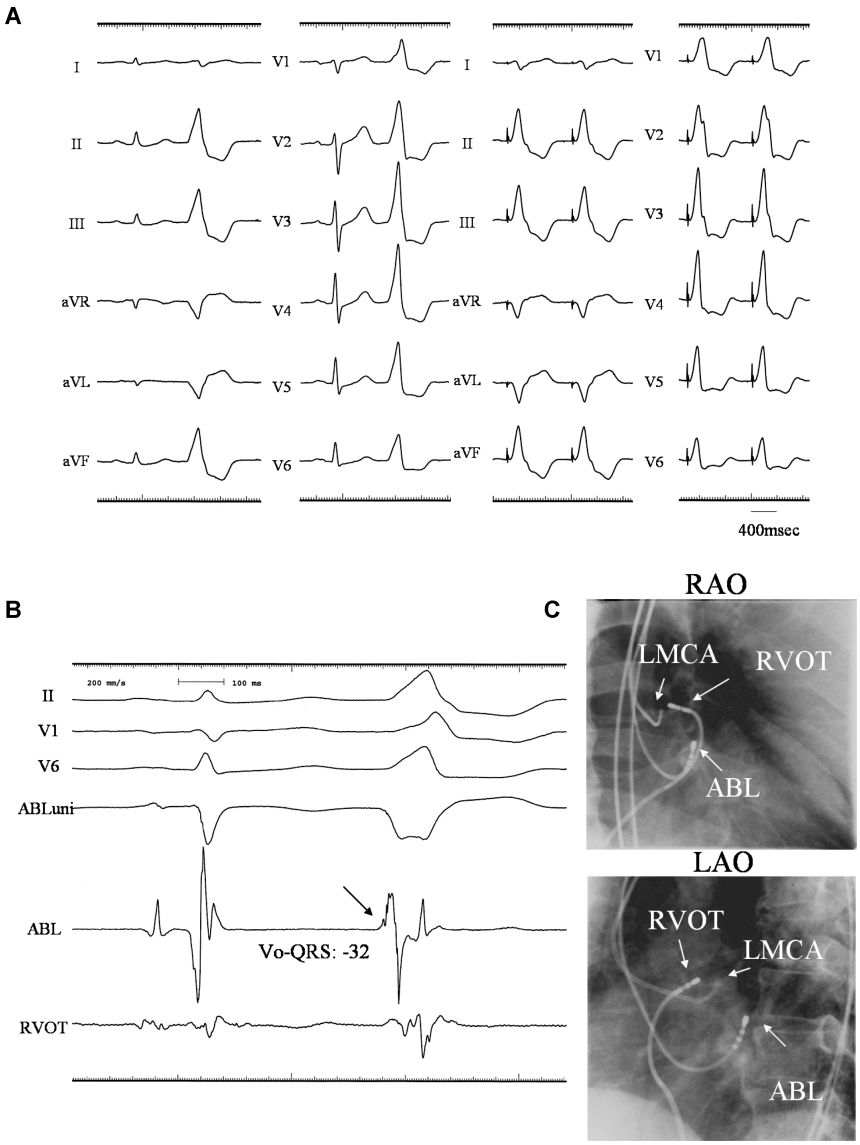

Figure 4. *The ECG recordings obtained during the EP study and catheter position at the successful ablation site (RAO35°and LAO45°) in a patient with AMC-VTs. (A) A pace map with a near-perfect match. (B) The earliest activation (prepotential, arrow) preceded the QRS onset (Vo) by 32 ms during a VPC. (C) The location of the ablation catheter is just below the AMC of the mitral annulus. Note that the left Judkin's catheter is located at the ostium of the left main coronary artery (LMCA).*

beneath the aortic valve.[9] The distribution of the septal myocardial origins beneath the aortic valve might contribute to the broad precordial transition and the various morphologies in leads I and V1.

EP Study and RFCA

The success rate of the RFCA for repetitive monomorphic VTs with a delta wave-like onset was not high due to the depth of the origin in the subendocardium.[18] However, in the present study, a high success rate was achieved for all types of LVOT-VTs except for Epi-VTs. This was because we were able to find a site in which both the atrial and ventricular potentials were simultaneously recorded during sinus rhythm accompanied by prepotentials during the ventricular tachycardia or VPCs, in addition to a perfect or near-perfect match of the pace map.[19] Thus, our tactics of a suitable selection for the application site may also work for all types of LVOT-VTs except for Epi-VTs. This prepotential could be a marker for a successful RFCA of LVOT-VTs. Ouyang *et al*. reported that a low-amplitude, high-frequency potential preceded the onset of the QRS complex in patients with Cusps-VT, suggesting a slow conduction area between the ventricle and ASC.[20] However, the mechanism of the prepotential recorded at the successful site in anterior MA-VTs and AMC-VTs remains unknown. Further studies are needed on the diagnostic significance of the prepotential.

TABLE 1

The Electrocardiographic Characteristics of the 12 Lead ECG in Anterior MA-VT/VPCs and AMC-VT/VPCs

		Transitional Zone	I	aVF	V1	V2	V3	V4	V5	V6
Anterior MA-VT/VPCs	1	V2	rs	R	rS	RS	RS	Rs	R	R
	2	V1	rS	R	R	Rs	Rs	Rs	R	R
	3	V1	rS	R	R	R	Rs	Rs	R	R
	4	V1	rS	Rs	Rs	Rs	Rs	Rs	R	R
	5	V1	S	R	Rs	Rs	Rs	Rs	Rs	R
	6	V1	rs	R	R	RS	Rs	Rs	Rs	Rs
	7	V2	S	R	Rs	RS	RS	Rs	Rs	R
	8	V2	S	R	QS	Rs	Rs	R	R	R
AMC-VT/VPCs	1	V1	rS	R	R	R	Rs	R	R	R
	2	V1	rS	R	R	R	R	R	R	R
	3	V1	Rs	R	R	R	R	R	R	R

MA = mitral annulus; AMC = aortomitral continuity; VT = ventricular tachycardia; VPCs = ventricular premature contractions.

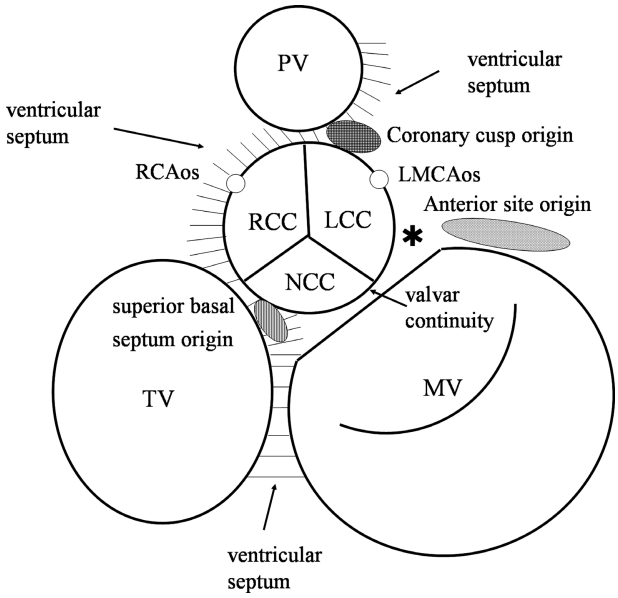

Figure 5. *The sites of origin of the LVOT-VTs are illustrated. This figure is viewed from the base of the ventricles. The asterisk represents the origin of AMC-VTs. LCC = left coronary cusp; RCC = right coronary cusp; NCC = non coronary cusp; AV = aortic valve; MV = mitral valve; TV = tricuspid valve; PV = pulmonary valve; LMCAos = the ostium of the left main coronary artery; RCAos = the ostium of the right coronary artery.*

Limitations of the Study

In the present study, we were unable to evaluate the ECG characteristics of the patients with superior basal septal or epicardial origin VTs due to the small number of patients. In this study, successful RFCA sites were considered to be the sites of the LVOT-VTs origin. However, it is possible that the different QRS morphology of those VTs might depend on the different exit sites from a single origin.

Conclusions

The AMC, which was a part of the LVOT, was located adjacent to the anterior site of the MA and ASC. All the variants of LVOT-VTs originating from those sites except for those with an epicardial origin were successfully treated with endocardial RFCA combined with pace mapping and the earliest ventricular electrogram with prepotential. Despite many morphological similarities among the variants of LVOT-VTs, those electrocardiographic characteristics may enable us to differentiate the variants of LVOT-VTs in order to safely perform RFCA.

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