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Is the activation potential of Mahaim pathway always a fast potential? Implication for radiofrequency catheter ablation

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Abstract **Introduction** Accessory pathways (AP) exhibiting Mahaim physiology are amenable to radiofrequency (RF) catheter ablation. The recording of an AP potential is an excellent guide for selection of ablation site. The purpose of this study is to determine whether the pathway potential is always a fast potential.
Methods Ten patients (six females, mean age, 30±12 years) with preexcited tachycardias involving a Mahaim pathway underwent electrophysiological study and subsequent attempts at RF ablation. Mahaim potentials (M-potential) recorded at the site of successful ablation were reviewed and classified by at least two reviewers.
Results In all patients, Mahaim pathways were characterized as atriofascicular types. The M-potential was fast in seven patients (group one), and slow in the remaining patients (group two). All group two patients had a history of prior failed ablation. Atrial electrograms were recorded closer to the QRS onset in group one. Atrium to fast M-potential (42±15 ms) was shorter than atrium to slow M-potential (83±12 ms, $P=0.03$) but M-potentials were recorded with similar distance before local ventricular electrogram (P=NS). Ablation was successful in all patients with mean of 2.9±1.4 RF applications per patient. Ablation data were similar between the two groups (P=NS). No complications occurred. During 12 months of follow-up, no recurrence was observed.
Conclusion Our results illustrated that the activation potential of Mahaim pathways is not always a fast potential. One-third of Mahaim pathways can be

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mapped and ablated when the slow type of M-potential was used as a target for ablation. We also confirmed high efficacy of catheter ablation of Mahaim pathways guided by activation potentials.

Introduction

In a series of papers published between 1932 and 1947, Mahaim and his co-workers originally described anatomical connections of the atrioventricular (AV) node to the bundle branches or ventricular myocardium, bypassing the His bundle, in pathological specimens [1—3]. The true nature of these pathways was first characterized by Klein and Tchou at almost the same time [4,5]. Currently, it is demonstrated that these pathways located in the right atrium (crossing the tricuspid annulus on the free wall rather than the septum). These pathways are comprised of tissue with basal long conduction times, have decremental conduction only in the antegrade direction, and demonstrate transient block following adenosine administration.

Today, radiofrequency catheter ablation (RFCA) has replaced the surgical interruption of these pathways with good results. Because they have different anatomical and electrophysiological properties, several techniques have been proposed for mapping and ablation of these pathways: (1) activation mapping of the pathway potential at the tricuspid annulus (TA) [6,7]; (2) finding the atrial site from which stimulation produces the shortest stimulus—QRS interval (pace mapping) [8,9]; (3) activation mapping of the pathway's ventricular insertion [10]; (4) finding a site at which mechanical trauma produces transient accessory pathway (AP) conduction block (bump mapping) [11]. The first method was considered to be more accurate than the others [7]. It has been based on recording of the activation potential of the Mahaim pathway (M-potential) which has been considered to be a high frequency fast potential. Our study questioned this assumption and presents two types of M-potential.

Methods

Patient characteristics

Between December 2001 and March 2003, 160 consecutive patients with atrioventricular accessory pathways underwent radiofrequency catheter ablation at our institution. Of these, 10 (6.2%) patients had atrioventricular reentrant tachycardias (AVRT) involving a Mahaim pathway as the antegrade limb of reentry. Six of the patients were female; the mean age was 30 ± 12 years (range 16.0—48.0 years). All patients had experienced symptomatic spontaneous tachyarrhythmias. Symptoms included disabling palpitations, dizziness, and presyncope. The duration of symptoms ranged from 5 to 15 years. Before referral to our institution, all patients had undergone drug trials with a median of three antiarrhythmic agents (range 1—5); In four patients, previous RFCA performed at other institutions had failed to eliminate conduction through these pathways. All repeat procedures were performed at least 3 months (range 3—8 months) after prior failed ablation attempts.

Electrophysiological study

All patients gave written informed consent for the procedures of electrophysiological study and RFCA. The protocol had been approved by the Ethics Committee at our institution. The patients were studied in the postabsorptive state and after all antiarrhythmics had been discontinued for at least five half-lives.

Electrophysiological study was performed using standard methods. Briefly, three standard 6F quadripolar catheters with 5-mm interelectrode distance (Daig, St. Jude Medical Inc., Minnetonka, MN, USA), were introduced through the femoral veins, and were advanced under fluoroscopic guidance to the right atrium, the right ventricular (RV) apex, and the bundle of His, respectively. In all patients undergoing the standard procedure, a 7F decapolar catheter with 2/2/2 mm electrode spacing (Marinr® CS; Medtronic, Inc., Minneapolis, MN, USA) was positioned retrogradely via the right femoral vein into the coronary sinus for coronary sinus mapping. For mapping of the tricuspid annulus (TA) and eventual ablation of the AP, a steerable 7F quadripolar catheter with 2/5/2 mm electrode spacing and 4-mm distal tip (Conductr® MC; Medtronic, Inc.) introduced by way of the right femoral vein was used. The TA was mapped during atrial pacing.

Twelve lead surface ECG and bipolar filtered electrograms (30—500 Hz) and unipolar unfiltered electrograms were recorded, displayed, and stored on an electrophysiological recording system (EPMed systems, Inc. West Berlin, NJ, USA). Programmed atrial and ventricular stimulation with stimuli of 1.0-ms duration at twice diastolic threshold was performed with the stimulator (Model EP-3 clinical stimulator, EPMed Systems Inc.). Criteria to locate the target site for RF current application was activation mapping of the pathway potential at the TA.

Definitions

Atriofascicular Mahaim pathway: AP was characterized as atriofascicular when ventricular activation at the right ventricular apex near the distal right bundle branch preceded activation at the TA.

Fast and slow M-potentials: the type of M-potential was defined visually. All intracardiac electrograms at the successful ablation sites were independently reviewed by two electrophysiologists (MH and AA) who were blinded to the patient's other data. In case of discordant judgment of the type of M-potential, the final diagnosis was made by consensus of three electrophysiologists (MH, AA, and MS).

Ablation

Ablation was attempted with the use of a 484-kHz continuous-wave current generator (Atakr® II; Medtronic Inc.). RF application was performed with a power limit of 50 W and temperature of 60 °C during atrial pacing to maintain maximal preexcitation. RF energy was applied for 120 s at each successful ablation site or for only 10 s when there was no apparent change in the degree of preexcitation. Energy delivery was stopped sooner if there was inadvertent catheter movement or a marked impedance rise. The ablation procedure was considered successful if, at the end of impulse delivery and 30 min later, AP conduction was abolished. During the procedure, patients were sedated, if necessary, with midazolam (1—3 mg) and/or morphine sulphate (3—6 mg).

RFCA was performed using the 45° left anterior oblique radiographic projection in the recording site of the M-potential at the TA. Long sheath-introducers (SR3 and SR4, Daig, St. Jude Medical Inc.) were used in some procedures to stabilize better the ablation catheter.

An electrophysiological evaluation was performed 30 min after ablation. It consisted of right atrial and ventricular stimulation with use of the extrastimulus technique as well as incremental pacing to exclude the presence of other APs and recurrence of Mahaim pathway conduction and to determine the postablation conduction properties of the AV node-His bundle system.

Follow-up

After RFCA, patients were followed in the arrhythmia clinic of our hospital. The first visit was planned 1 month after ablation. Then, patients were seen once or twice per year.

Statistical analysis

Data are presented as mean ± SD and with ranges when appropriate. Significance of continuous parameters was assessed by independent sample Student's *t*-test. Discrete variables were compared by chi-square test (or Fisher's exact test if applicable). A two tailed P-value < 0.05 was defined as statistically significant. The software SPSS version 12.0 (SPSS Inc., Chicago, IL, USA) was used for statistical analysis.

Results

Electrocardiographic findings

From 160 patients with AVRT, ten patients met the criteria for diagnosis of Mahaim pathway. In eight patients, no preexcitation was seen in sinus rhythm. Ventricular preexcitation was observed in the remaining two patients during sinus rhythm. At the baseline, mean values of PR interval, QRS duration, and QT interval were 133 ± 26 ms, 90.7 ± 25.4 ms, and 334 ± 24.8 ms, respectively.

Electrophysiological findings

The clinically documented arrhythmias were antidromic AVRT in all patients; in one patient (with Ebstein's anomaly), orthodromic AVRT incorporating a right posteroseptal AP had also been documented. In nine cases, Mahaim pathways were the only documented AP. In our last patient, a nonsustained episode of right ventricular outflow tract tachycardia was induced in association with antidromic AVRT. In all cases, Mahaim pathways were characterized as atriofascicular types.

Mapping and ablation data (Table 1)

The TA was mapped during atrial pacing. The recording site of the M-potentials in the TA

Table 1 Electrophysiological data of studied patients at the site of successful ablation

Parameters	Group one[a]	Group two[b]	*P* value
A-MP interval (ms)	42±15	83±12	0.03
MP-V interval (ms)	78.3±12.1	74.3±10.6	0.55
A-QRS onset (ms)	106.6±7.3	123.3±12.6	0.026
MP amplitude (mV)	0.30±0.05	0.27±0.05	0.41
MP duration (ms)	9.3±1.1	35.6±3.0	0.0001
A/V ratio	0.31±0.05	0.26±0.02	0.17
RF time to AP conduction block (s)	8±2	8.2±3	0.56

MP, Mahaim potential; A, atrial electrogram; V, ventricular electrogram; A/V ratio, ratio of amplitude of atrial to ventricular electrograms; AP, accessory pathway.
[a] Ablation sites with a fast Mahaim potential.
[b] Ablation sites with a slow Mahaim potential.

was aimed for ablation in all patients. M-potentials were fast and spiked (9.3±1.1 ms) in seven patients and slow and wide (35.6±3.0 ms) in three patients ($P=0.0001$) (Figs. 1 and 2). Slow M-potentials were recorded in three of four patients with previously failed procedures and none of the initially successful procedures ($P=0.033$). Fast M-potentials were recorded closer to the atrial electrogram than slow M-potentials (42±15 vs. 83±12 ms, $P=0.03$). The interval between the M-potential and the local ventricular potential was similar in patients with both types of M-potentials (78.3±12.1 vs. 74.3±10.6 ms, $P=0.55$). Atrial to QRS complex onset was longer at the ablation site of the slow M-potentials (123.3±12.6 vs. 106.6±7.3, $P=0.026$). The ratios of atrial to ventricular electrograms (A/V ratio) and M-potential amplitude were similar at the ablation sites of both types of M-potentials ($P=0.17$ and $P=0.41$, respectively).

Mahaim pathways were located in the lateral region of the tricuspid valve in six patients, anterolateral region in one patient, and posterolateral region in three patients (Fig. 3). Ablation was successful in all patients. RF delivery at the M-potential recording site resulted in accelerated preexcited rhythm in all cases. The mean number of RF applications was for fast M-potentials: 2.7±1.3 vs. slow M-potentials: 3.0±1.7, mean fluoroscopy time was for fast M-potentials: 34±13.3 min vs. slow M-potentials: 35.2±12.5 min), mean procedure time was for fast M-potential: 84.8±22 min vs. slow M-potentials: 78±27.7 min), and RF delivery time to AP conduction block in the successful ablation site was for fast M-potentials: 8±2 s vs. slow M-potentials: 8.2±3 s. These data were similar in the two groups (all *P* values >0.05). No complications occurred in any patient.

After a mean duration of 12±3 months of follow-up, all patients were asymptomatic and no recurrence had occurred.

Discussion

Mahaim pathways comprise 3–5.9% of APs in the literature. In our series, prevalence of these APs corresponded approximately to the upper limit of this range (6.2%). This higher prevalence might be related to the fact that our centre receives tertiary referrals.

With the evolution of electrophysiology, treatment strategies have been changed from pharmacological therapy to catheter ablation and surgical disconnection. RFCA of Mahaim pathways has revolutionized the therapy of these AVRTs in the last decade. The distal insertion of the Mahaim pathway is located away from the tricuspid ring, thus mapping of the TA for earliest ventricular activation cannot be used for ablation. On the other hand, these pathways have no retrograde conduction, thus mapping for the site of earliest retrograde atrial activation is impossible. Several strategies have been proposed to identify appropriate target sites for catheter ablation as previously described. From these methods, activation mapping of the pathway potential at the TA is the best and most accurate method for selecting the target site of Mahaim pathway ablation. In this method, the mapping catheter was moved around the TA during atrial pacing or tachycardia, seeking the activation potential of the Mahaim pathway.

Cappato et al. [11] reported that the recording site of the M-potential coincided with the atrial insertion of the AP in all cases and no such potential could be recorded in 33% of their patients. These investigators did not notice the presence of different types of M-potential. In accord with this study, no fast potential was recorded along the TA in 30% of our cases. In these patients, a slow potential was recorded and targeted for ablation. McClelland et al. [6] have reported relatively large series of catheter ablation of Mahaim pathways. Of the 23 patients with atriofascicular pathways, the activation potential was recorded in 22 cases and the final success rate of 100% was achieved with a mean of 3.2±2.9 RF applications. Grogin et al. [12] obtained a similarly

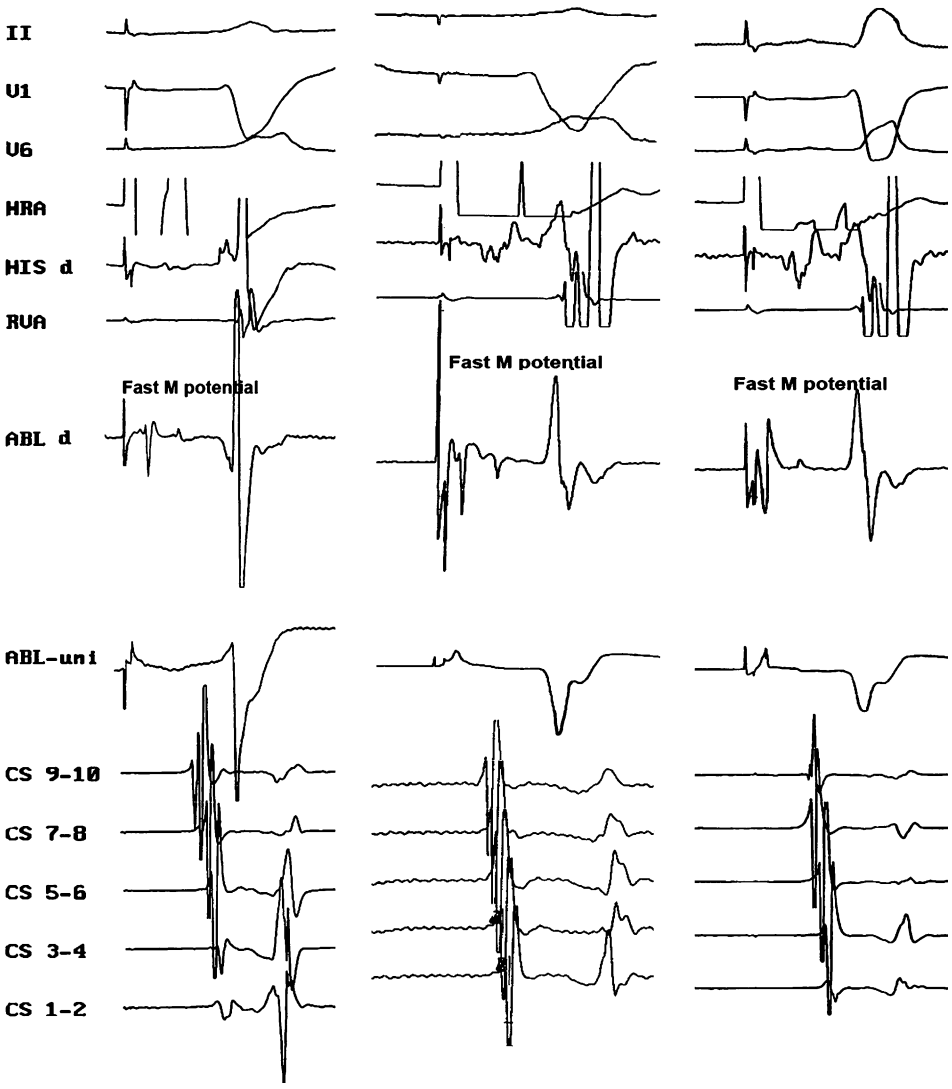

Figure 1 Electrophysiological tracing of three patients with fast Mahaim potentials. HRA, high right atrium; HIS, his bundle; RVA, right ventricular apex; ABL, ablation; CS, coronary sinus.

high success rate using this method with a mean of 10 RF applications. In the study of Brugada et al. [13], the recording site of discrete potentials was reported as the optimal target for RF application. They achieved a success rate of 100% with a mean of seven RF applications in four patients. Similar results were obtained by Silva et al. [7] in six patients with a mean of 5.3 ± 3 RF applications.

In all of the above-mentioned studies, the M-potential was defined as a discrete and fast potential. Our study showed that this is not always the case. In 30% of our patients, a fast potential could not be recorded. Instead, a slow type of M-potential was mapped at the site of successful ablation. Several explanations could be responsible for the presence of different morphologies of M-potentials: (1) differences in the ablation site (annular vs. more ventricular); (2) endocardial vs. subendocardial pathway; (3) farfield effect due to inadequate ablation catheter position; (4) changes in conduction time due to previous radiofrequency applications; and (5) presence of different cell types. Our hypothesis is that the different morphologies of M-potential (fast and slow) are determined by the conduction time over the structure recorded but do not indicate a specific cell type. It is possible to have ''slow'' conduction after injury to a structure that initially had ''fast'' conduction (as from injury by prior ablation attempts). This hypothesis was supported by the fact that in our series slow M-potentials are only recorded in the patients with history of prior failed ablation. It is possible that slow represents ''AV nodal-like cells'' and that fast represents ''His bundle like'' structures but this remains speculative [14]. Similarity of the A/V ratio at the ablation

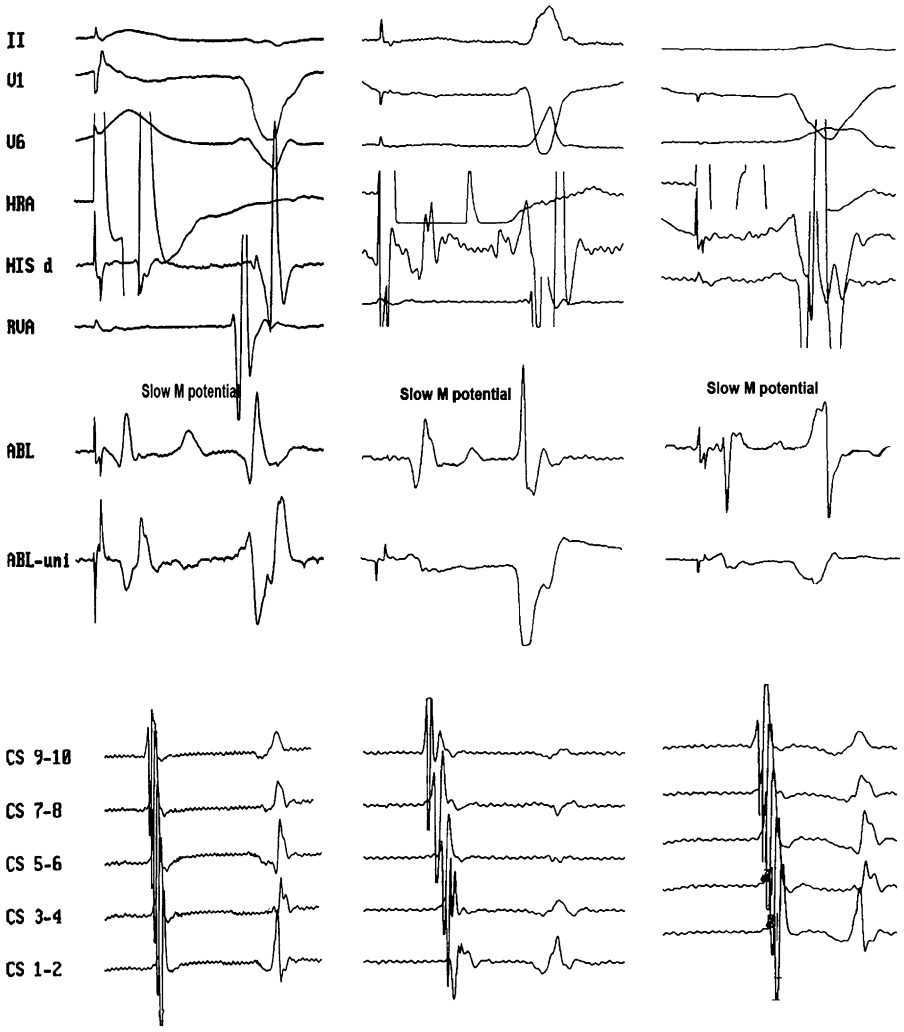

Figure 2 Electrophysiological tracing of three patients with slow Mahaim potentials. HRA, high right atrium; HIS, his bundle; RVA, right ventricular apex; ABL, ablation; CS, coronary sinus.

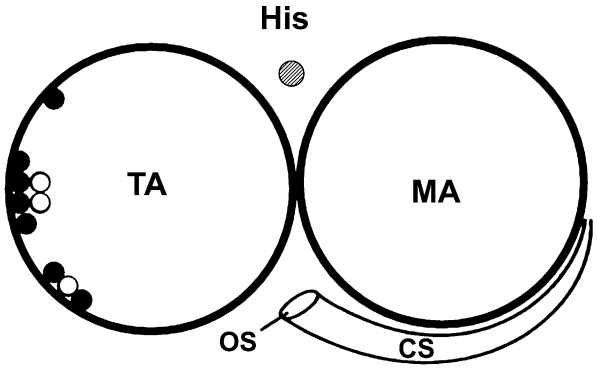

Figure 3 Schematic representation of anatomical sites of ablation along the TA in LAO view (black and empty circles indicate ablation sites of fast and slow M potentials, respectively). TA, tricuspid annulus; MA, mitral annulus; HIS, his bundle; CS, coronary sinus; OS, ostium.

site and time to AP conduction block following RF application ruled out differences in the ablation site and depth of AP location or farfield effect as possible explanations. Thus, we think these two different potentials permit identification of a single anatomical area in the reentrant circuit of AVRT, as demonstrated by the effectiveness of RF ablation using both these targets.

Limitations

Our study was limited by the fact that we did not assess the effects of physiological and pharmacological interventions on the electrophysiological properties of slow M-potentials. Although these manoeuvres could provide further insight into the properties of these potentials, different morphologies and intervals to the atrial electrogram were

all in favour of a distinct nature of these potentials.

Conclusions

Our results illustrated that the activation potential of the Mahaim pathway is not always fast. One-third of Mahaim pathways can be mapped and ablated when a slow type of M-potential was used as a target for ablation. We also confirmed high efficacy of catheter ablation of Mahaim pathway guided by the activation potential.

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