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P-Wave Morphology in Focal Atrial Tachycardia

Development of an Algorithm to Predict the Anatomic Site of Origin

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OBJECTIVES The purpose of this study was to perform a detailed analysis of the P-wave morphology (PWM) in focal atrial tachycardia (AT) and construct and prospectively evaluate an algorithm for identification of the anatomic site of origin.

BACKGROUND Although smaller studies have described the PWM from particular anatomic locations, a detailed algorithm characterizing the likely location of a tachycardia associated with a P-wave of unknown origin has been lacking.

METHODS The PWMs for 126 consecutive patients undergoing successful radiofrequency ablation of 130 ATs are reported. P waves were included only when the onset was preceded by a discernible isoelectric segment. P waves were classified as positive (+), negative (−), isoelectric, or biphasic. Sensitivity, specificity, and predictive values were calculated. On the basis of these results, an algorithm was constructed and prospectively evaluated in 30 new consecutive ATs.

RESULTS The distribution of ATs was right atrial (RA) in 82 of 130 (63%) and left atrial (LA) in 48 of 130 (37%). Right atrial sites included crista (n = 28), tricuspid annulus (n = 29), coronary sinus (CS) ostium (n = 14), perinodal (n = 7), right septum (n = 1), and RA appendage (n = 3). Left atrial sites included pulmonary veins (n = 32), mitral annulus (n = 8), CS body (n = 3), left septum (n = 3), and LA appendage (n = 2). In electrocardiographic lead V_1, a negative or +/− P-wave demonstrated a specificity of 100% for a RA focus, and a + or −/+ P-wave demonstrated a sensitivity of 100% for a LA focus. A characteristic PWM was associated with high sensitivity and specificity at common atrial sites for tachycardia foci. A P-wave algorithm correctly identified the focus in 93%.

CONCLUSIONS Characteristic PWMs corresponding to known anatomic sites for focal AT are associated with high specificity and sensitivity. A P-wave algorithm correctly identified the site of tachycardia origin in 93%. (J Am Coll Cardiol 2006;48:1010–7) © 2006 by the American College of Cardiology Foundation

Focal atrial tachycardia (AT) is a relatively uncommon cause of supraventricular tachycardia and is difficult to treat medically. Fortunately, with the advent of radiofrequency ablation (RFA), this form of tachycardia can be treated with high long-term success (1,2). It is well-recognized that these foci do not occur randomly throughout the atria but tend to cluster at characteristic anatomic locations. In the right atrium (RA), these foci occur along the crista terminalis (CT) (1,3), the tricuspid annulus (TA) (4), the ostium of the coronary sinus (CS) (5), and the perinodal region. In the left atrium (LA), foci occur predominantly at the pulmonary vein (PV) ostia (6) and less commonly at the mitral annulus (MA) (7), the left atrial appendage (LAA), and the left-sided septum (8).

In recent years, mapping of these foci has evolved from the use of single- or double-catheter techniques with leap-frogging, through high-density multipolar mapping, to the use of sophisticated 3-dimensional mapping tools. Although contact and noncontact mapping systems (3) are effective in targeting ablation of AT, in the majority of labs they complement rather than replace conventional electrophysiologic techniques. However, although detailed and often expensive mapping techniques remain the cornerstone of identifying tachycardia origin and ablation success, it should not be forgotten that much initial information can be gleaned from a careful analysis of the P-wave. Although a variety of studies have described the P-wave morphology (PWM) from a particular anatomic location, a detailed algorithm characterizing the likely location of a tachycardia associated with a tachycardia P-wave of unknown origin has been lacking. We present a detailed analysis of the PWM according to anatomic site of tachycardia origin and use this to construct an algorithm to localize the tachycardia. We then apply this algorithm prospectively in order to evaluate its clinical utility.

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METHODS

Study population. The study population included a consecutive series of 186 patients (65% female, mean age 49 ± 17 years, range 9 to 85 years) undergoing RFA for focal origin of 196 ATs. All patients had clinically documented

Abbreviations and Acronyms

AT = atrial tachycardia
CS = coronary sinus
CT = crista terminalis
ECG = electrocardiogram
LA = left atrium
LAA = left atrial appendage
LIPV = left inferior pulmonary vein
LSVP = left superior pulmonary vein
MA = mitral annulus
NPV = negative predictive value
PPV = positive predictive value
PV = pulmonary vein
PWM = P-wave morphology
RA = right atrium
RAA = right atrial appendage
RFA = radiofrequency ablation
RIPV = right inferior pulmonary vein
RSPV = right superior pulmonary vein
SR = sinus rhythm
SVC = superior vena cava
TA = tricuspid annulus

paroxysmal or incessant AT. Patients with multiple changing AT morphologies were excluded.

All patients underwent electrophysiological study after the provision of informed written consent. The study was approved by the Melbourne Health Research Ethics Committee. Patients were studied in the fasted awake state with minimal use of sedation. All antiarrhythmic drugs were ceased a minimum of 5 half-lives before the procedure.

Catheter positioning. Catheter positioning and the approach used in our laboratory for ablation of AT have been previously and extensively published (6). Standard electrophysiologic criteria were used to diagnose AT; these included the inability to demonstrate entrainment at 2 locations which are, "in the tachycardia circuit," 2 cm apart (9). Attempts at AT induction were made including atrial programmed extrastimulation and burst atrial pacing. If this was unsuccessful or when AT was not occurring spontaneously, isoproterenol was infused.

Mapping of AT. Anatomic localization of the atrial focus was performed during tachycardia or atrial ectopy by analysis of: 1) surface electrocardiogram PWM; and 2) RA endocardial activation sequence during tachycardia (1,4,7).

On the basis of the provisional findings from PWM and the right atrial endocardial sequence from standard catheters, point mapping to locate the site of earliest endocardial activation relative to surface P-wave onset was performed with a 4-mm-tip mapping/ablation catheter. A fiducial point on a stable intracardiac electrode, usually the CS catheter, relative to P-wave onset was defined to perform point mapping.

Anatomic definition. Anatomic definitions were as previously described for the CT (1), CS ostium (5), tricuspid (4) and mitral (7) annuli, and the PVs (6).

CT. Earliest activation mapped to this region with 20-pole catheter positioned along the CT.

SEPTUM. Defined as the region of the fossa ovalis and septum primum. Atrial tachycardia originating within Koch's triangle were separately classified as perinodal or arising from the CS ostium.

PERINODAL. Earliest activation recorded in the proximal His bundle electrode; RFA successful within 1 cm of this region.

Definitions of AT arising from the CS ostium, MA and TA, and PVs have been previously published (4–7).

PWM. Surface 12-lead electrocardiographic PWM was assessed as previously described (10). Particular attention was given to assessment of an unencumbered P-wave by analysis during periods of atrioventricular block or after ventricular pacing. P waves were included for analysis only if an isoelectric interval was present and there was no fusion with the preceding QRS or T-wave. P waves were assessed at 0.3 mV and described on the basis of the deviation from baseline during the

Table 1. P-Wave Morphology for Right Atrial Focal Atrial Tachycardia

Site	ECG Lead							
	I	II	III	aVL	aVR	V_1	V_3	V_6
CT	+(28)	+(28)	+(23)	−(17)	−(28)	+/−(19)	+(27)	+(27)
			iso(4)	iso(8)		+(7)	iso(1)	iso(1)
			−(1)	+(3)		−(2)		
TA	+(17)	−(18)	−(22)	+(24)	+(15)	−(28)	−(22)	iso(9)
	iso(9)	+(7)	+(6)	−(2)	−(9)	+/−(1)	−/+(4)	neg(6)
	iso/+(3)	−/+(2)	iso(1)	iso(2)	+/−(2)		iso(3)	pos(6)
		iso(2)		−/+(1)	iso(3)			iso/+(4)
								−/+(4)
CS ostium	iso(12)	−(14)	−(14)	+(14)	+(14)	iso/+(6)	−(9)	−(10)
	low+(2)					−/+(6)	−/+(3)	iso(2)
						−(2)	iso(2)	−/+(2)
Perinodal right septum	iso(5)	−(5)−/+(1)	−(5)−/+(1)	+(7)	+(6)	iso(3),−(1)	−(4)	−(6)
	+(1),−/+(1)	iso(1)	iso(1)		iso(1)	+/−(1)−/+(1)	iso(3)	iso(1)
	+(1)	+(1)	+(1)	−(1)	−(1)	iso(1)	+(1)	+(1)
RAA	+(2)	+(3)	+(3)	−(2)	−(3)	−(3)	−(2)	iso(1)
	iso(1)			iso(1)			iso(1)	+(1),−(1)

CS = coronary sinus; CT = crista terminalis; ECG = electrocardiographic; RAA = right atrial appendage; TA = tricuspid annulus.

Table 2. P-Wave Morphology for Left Atrial Focal Atrial Tachycardia

Site	ECG Lead							
	I	II	III	aVL	aVR	V_1	V_3	V_6
RPV	+(14)	+(15)	+(14)	−(11) +(2)	−(14)	+(15)	+(15)	+(15)
	iso(1)		−(1) RIPV	+/−(2)	+(1)			
LPV	iso(12)	+(16)	+(16)	−(14)	−(15)	+(17)	+(17)	+(13)
	+(3),−(2)	−(1)	−(1)	iso(3)	iso(1) +(1)			iso(4)
	iso(7)	low+(5)	low+(5)	iso(6)	iso(7)	−/+(7)	−/+(6)	−/iso(2)
Superior MA	−(1)	iso(3)	iso(3)	−(2)	−(1)	iso/+(1)	−/iso(2)	iso(6)
LAA	−(2)	+(2)	+(2)	−(2)	iso(1) −(1)	+(2)	+(2)	iso(2)
CS body	iso(2) neg(1)	−(3)	−(3)	+(3)	+(3)	+(3)	−(2),+(1)	−(2),+(1)
Left septum	iso(1)	−/+(1)	−/+(1)	−(1)	+/−(1)	−/+(3)	−(3)	−(2)
	−/+(2)	−(2)	−(2)	+(2)	+(2)			iso(1)

LAA = left atrial appendage; LPV = left pulmonary vein; MA = mitral annulus; RIPV = right inferior pulmonary vein; other abbreviations as in Table 1.

T–P interval as being: 1) positive (+); 2) negative (−); 3) isoelectric: arbitrarily defined when there was no P-wave deviation from a baseline of ≥0.05 mV (7); and 4) biphasic (+/− or −/+). Sensitivity, specificity, positive predictive value (PPV), and negative predictive values (NPVs) were calculated for the most distinguishing features at each site.

DEVELOPMENT OF THE P-WAVE ALGORITHM

On the basis of the tabulated P-wave features for each anatomic location (Tables 1 to 3), an algorithm was developed to determine anatomic site of tachycardia origin. The algorithm was modified and tested against 20 P waves randomly selected from the original population until an accuracy of 95% was achieved. Anatomic structures that were within the known spatial limitations of PWM were grouped together.

Prospective application of the algorithm. The algorithm was subsequently prospectively applied, by 2 blinded observers, to a new population of 30 consecutive patients with focal AT who underwent successful RFA. An unencumbered tachycardia P-wave and a sinus P-wave selected from the successful electrophysiological study were assessed at 0.3 mV by each observer. The observer described the PWM as defined earlier and the algorithm was strictly followed.

Statistical analysis. All variables are expressed as mean ± SD. Comparisons between groups were performed with either an unpaired Student *t* test or, where a normal distribution could not be assumed, the Mann-Whitney *U* test. Categorical variables expressed as numbers and percentages were compared with a chi-square test. A p value <0.05 was considered statistically significant.

RESULTS

Tachycardia characteristics. ANATOMIC LOCATION. The anatomic distribution of 196 AT foci is presented in Figure 1. At the CT, the foci were superior in 47%, mid in 47%, and inferior in 6%. The distribution of tachycardia foci at the TA

Table 3. P-Wave Morphology

AT Location	P-Wave Morphology	Sensitivity	Specificity	PPV	NPV
Atrial location					
RA vs. LA1	+/− or − in V_1	69%	100%	100%	66%
RA vs. LA2	+aVL	58%	85%	87%	54%
RA vs. LA3	+I	67%	64%	76%	53%
RA vs. LA4	+/− or − in V_1 and + aVL	37%	100%	100%	47%
LA vs. RA1	+ or −/+ in V_1	100%	81%	76%	100%
LA vs. RA2	− aVL	62%	73%	57%	76%
LA vs. RA3	− or iso in I	60%	68%	53%	74%
LA vs. RA4	+ or −/+ in V_1 and − aVL	58%	95%	88%	79%
Anatomic location					
CT	+/− V_1 or if + in Tc then + in SR and all of +I, +II, −aVR	93%	95%	84%	98%
TA	− V_1 and + or iso aVL	83%	97%	89%	95%
RPV	+ V_1 (not bifid) and + in lead I	87%	94%	65%	100%
LPV	+ V_1 (bifid) and iso or − in I	82%	98%	88%	97%
Superior MA	−/+ V_1 and iso or − in aVL	88%	99%	88%	99%
CS ostium	−/+ or iso/+ in V_1 and − II, III, aVF_1 and + aVL	86%	98%	86%	98%
Perinodal and right septum	iso V_1	50%	100%	100%	97%

AT = atrial tachycardia; LA = left atrium; NPV = negative predictive value; PPV = positive predictive value; RA = right atrium; SR = sinus rhythm; other abbreviations as in Tables 1 and 2.

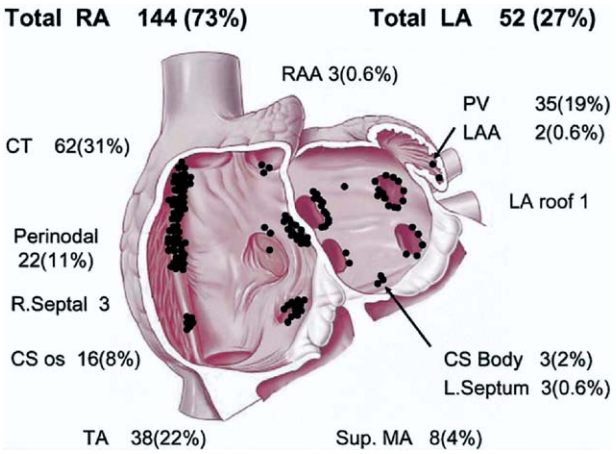

Figure 1. A schematic representation of the anatomic distribution of focal atrial tachycardias. The atrioventricular valvular annuli have been removed. CS = coronary sinus; CT = crista terminalis; LA = left atrium; LAA = left atrial appendage; MA = mitral annulus; PV = pulmonary vein; RA = right atrium; RAA = right atrial appendage; TA = tricuspid annulus.

and MA are demonstrated in Figure 2. Tachycardia foci arising from the PVs were localized to the right superior pulmonary vein (RSPV) in 15, to the left superior pulmonary vein (LSPV) in 12, to the left inferior pulmonary vein (LIPV) in 5, to the right middle pulmonary vein in 1, and to the right inferior pulmonary vein (RIPV) in 2, and were ostial in 31 of 35 (89%).

PWM. One hundred twenty-six patients with 130 focal ATs were included for analysis, with 66 ATs excluded because of incomplete isolation of the tachycardia P-wave from the preceding T-wave (47) or because ablation was not successful (19). The putative sites of the ATs not included in the analysis of PWM were CT (n= 34), right perinodal (n = 15), TA (n = 9), CS ostium (n = 2), right septum (n = 2), PVs (n = 3), and LA roof (n = 1).

RA VERSUS LA. The PWM for focal tachycardias arising in the right (Fig. 3) and left (Fig. 4) atria are presented in Tables 1 and 2, respectively. To assess the utility of the electrocardiogram (ECG) in differentiating left from right atrial origin of the tachycardia focus, we analyzed lead I, lead aVL, and lead V_1, which have been previously considered to be most useful for this purpose (10).

A detailed analysis is shown in Table 3. Some of the critical observations were as follows:

Either a negative or a biphasic (+/−) P-wave in lead V_1 was associated with a specificity of 100% for a right atrial tachycardia (Table 3).

A positive or −/+ P-wave in lead V_1 was associated with a sensitivity of 100% for a left atrial tachycardia (Table 3). Predictive accuracy was reduced by foci arising at or close to the interatrial septum, such as the high CT (positive P-wave) or ostium of the CS (−/+ or isoelectric/+).

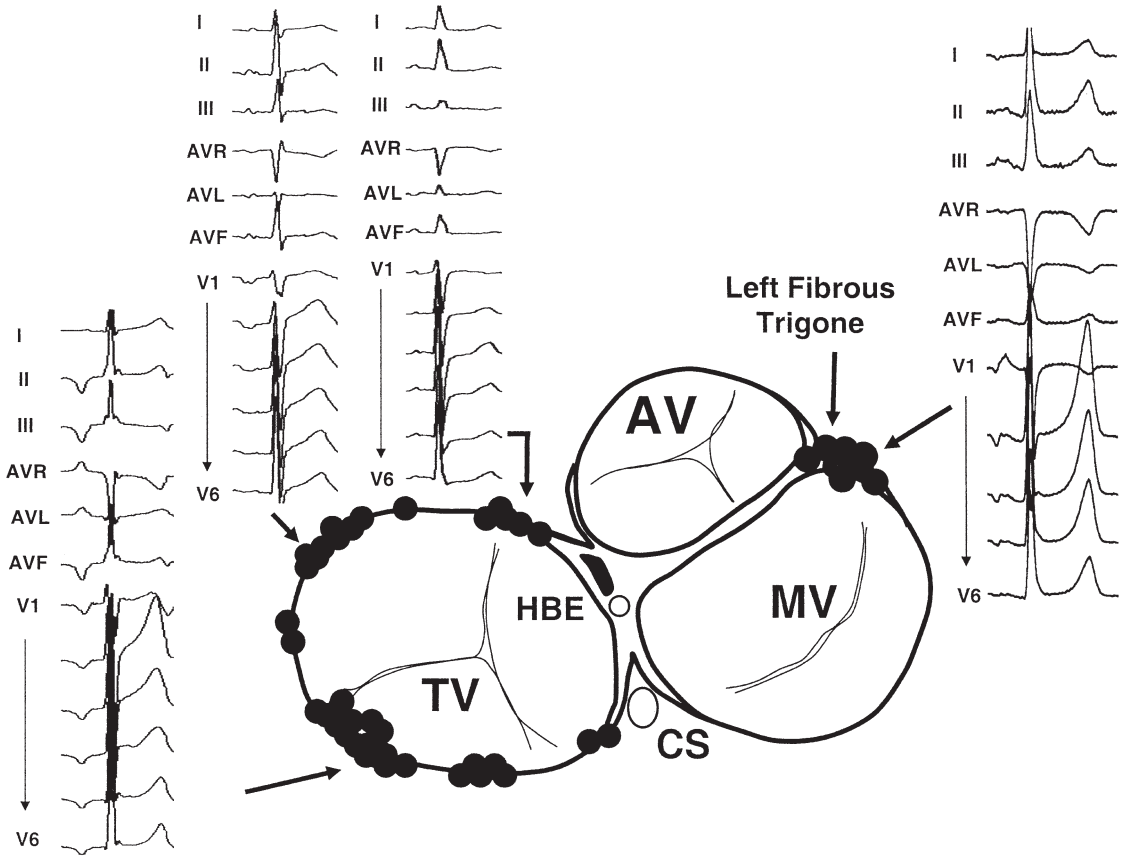

Figure 2. Anatomic distribution of tachycardia foci and tachycardia P waves at the atrioventricular valvular annuli. AV = atrioventricular; HBE = His bundle electrogram; MV = mitral valve; other abbreviations as in Figure 1.

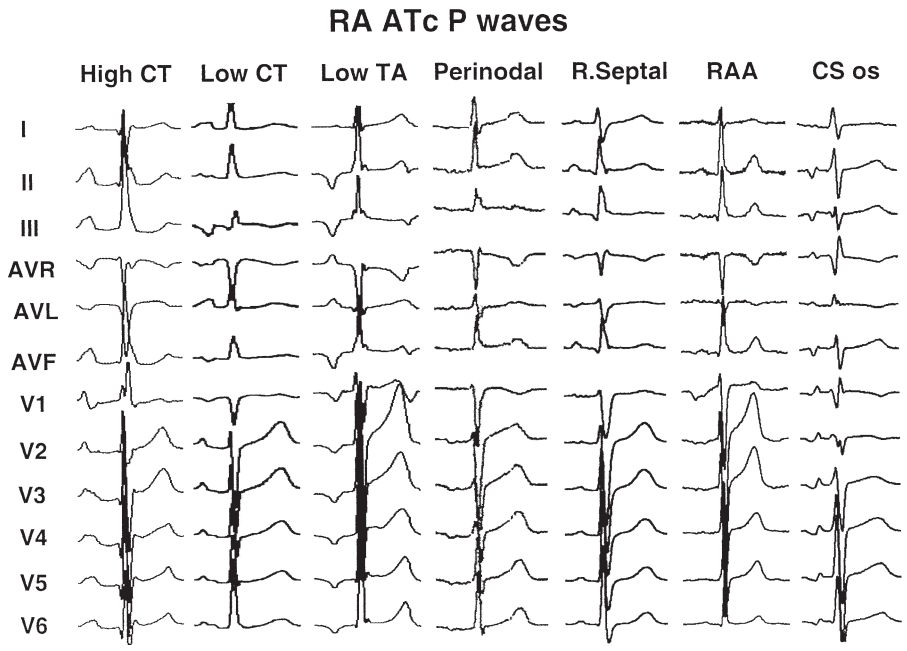

Figure 3. Representative examples of the tachycardia P-wave from right atrial sites. Abbreviations as in Figure 1.

Electrocardiographic leads aVL and I were less useful (Table 3).

Anatomic locations. CT. The comparison of V_1 between tachycardia and sinus rhythm (SR) was useful in helping to distinguish a high CT location from an RSPV focus, although significant overlap in PWM persisted. Of the 7 CT ATs positive in lead V_1, all 7 were positive in SR. All 14 RSPV foci were positive in V_1 during tachycardia. Of these, 9 were biphasic and 5 were positive in SR. Thus, in differentiating a superior CT focus from an RSPV focus, it was also helpful to look at the SR V_1 morphology (Table 3, Fig. 5). For CT foci, when V_1 was negative in tachycardia, the P-wave was also negative in SR (Table 3).

A PWM that included positive polarity in leads I and II, negative in aVR, and biphasic (positive-negative) in V_1 (and, if positive in V_1 in tachycardia, then also positive in SR) was associated with a sensitivity of 93%, a specificity of 95%, a PPV of 84%, and an NPV of 98% for foci at the CT.

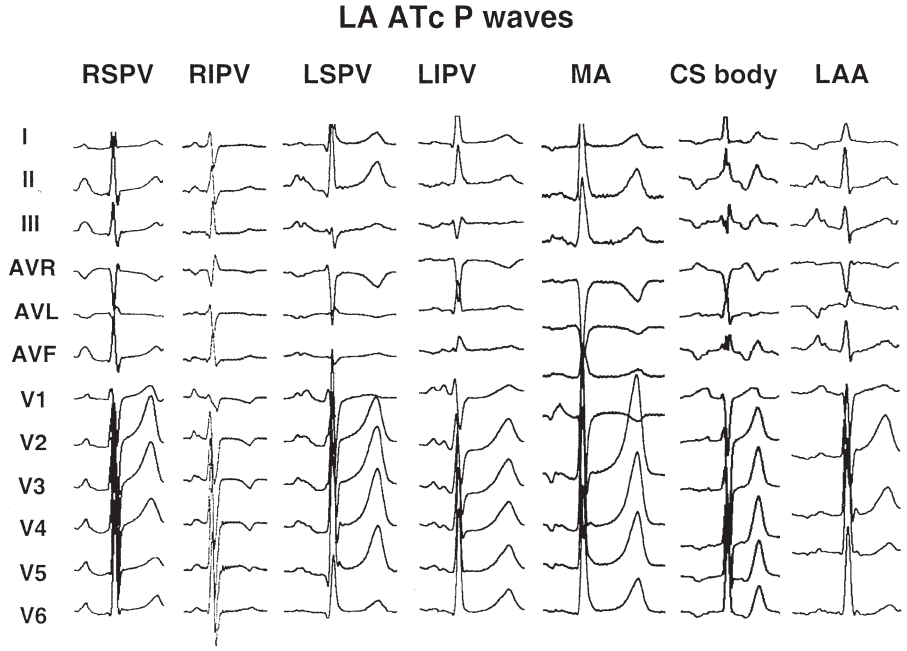

Figure 4. Representative examples of the tachycardia P-wave from left atrial sites. LIPV = left inferior pulmonary vein; LSPV = left superior pulmonary vein; RIPV = right inferior pulmonary vein; RSPV = right superior pulmonary vein; other abbreviations as in Figure 1.

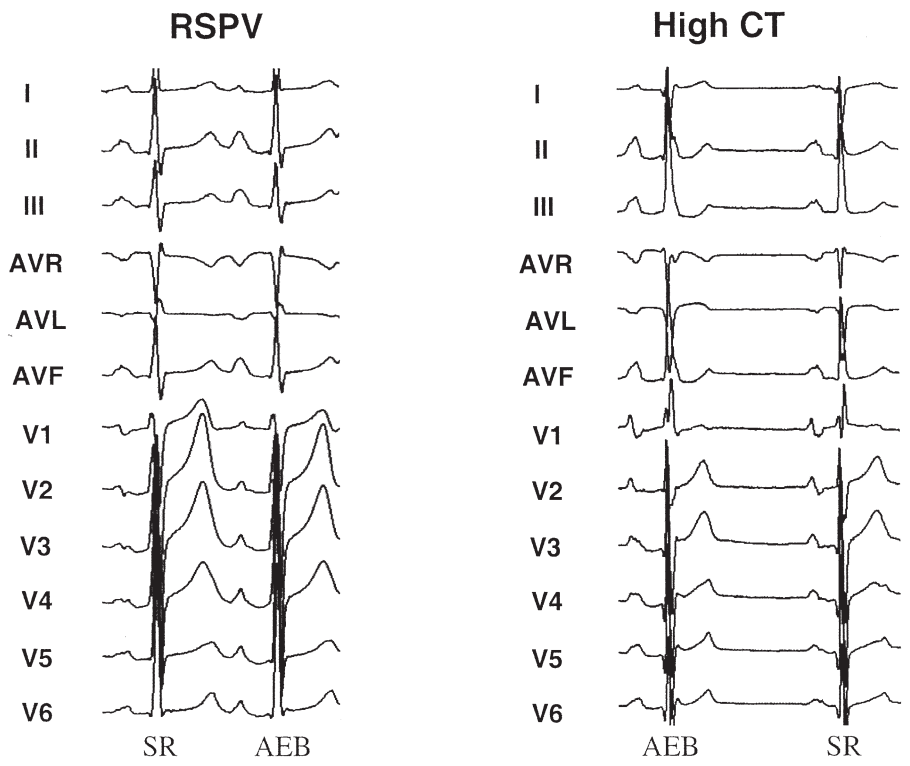

Figure 5. The P waves in sinus rhythm and atrial ectopy for the high crista and right superior pulmonary vein. Foci at the right superior pulmonary vein show a change in configuration in lead V_1 from biphasic in sinus rhythm to upright in tachycardia, a change not observed for right-sided tachycardias. SR = sinus rhythm; other abbreviations as in Figure 1.

TA. In this study, we observed that ATs can arise from anywhere around the annulus. Despite this wide anatomic distribution, a PWM that included negative polarity in lead V_1 and positive or isoelectric in aVL was associated with a sensitivity of 83%, a specificity of 97%, a PPV of 89%, and an NPV of 95% for AT foci at the TA.

Of note, in lead V_1, 23 of 29 TA ATs demonstrated a characteristically bifid negative morphology (Fig. 2). In general, the polarity of leads II and III was deeply negative for an inferoanterior location, and low amplitude, positive, or biphasic for a superior location (Fig. 2).

Tachycardia foci originating at the right atrial appendage (RAA) demonstrated a very similar PWM to the superior location of the TA (Table 1, Fig. 3).

CS OSTIUM. A PWM that was −/+ or iso/+ in lead V_1, negative in leads II, III, and aVF, and positive in aVL was associated with a sensitivity of 86%, a specificity of 98%, a PPV of 86%, and an NPV of 98%. Significant overlap was seen with AT foci at the left septum.

BODY OF CS. The P-wave was bifid positive in V_1, deeply negative in leads II, III, and aVF, positive in aVL, and negative in aVR in 3 of 3 patients.

PVs. For right-sided PVs, a PWM that was positive in leads V_1 to V_6 and positive in lead I was associated with a sensitivity of 87%, a specificity of 94%, a PPV of 65%, and an NPV of 100%. Significant overlap was seen with CT foci. In addition, 2 RSPV foci demonstrated P-wave notching in leads II and V_1, features generally associated with left-sided PVs. If criteria were added to include a change in lead V_1 from biphasic in SR to positive in tachycardia, the specificity improved to 100% but the sensitivity declined to 65%.

For left-sided PVs, a PWM that was isoelectric or negative in lead I and was bifid positive in lead II and/or V_1 was associated with a sensitivity of 82%, a specificity of 98%, a PPV of 88%, and an NPV of 97%. The exceptions were at the LAA, which resembled the LSPV location, and 3 LSPVs which were positive in lead I.

Some distinction between superior and inferior PVs could be made based on the P-wave amplitude in the inferior leads. In general, the P-wave for AT arising from inferior PVs was low-amplitude positive or negative (1 of 1 RIPV and 1 of 5 LIPVs).

LAA. For tachycardias arising from the LAA, PWM was similar to that of a left-sided PV. The presence of a deeply negative P-wave in lead I suggested an origin in the LAA.

SUPERIOR MA. A PWM that included a negative, then positive polarity in lead V_1 and was isoelectric or negative in aVL was associated with a sensitivity of 88%, a specificity of 99%, a PPV of 88%, and an NPV of 99%. The exceptions were 1 AT at the left septum and 1 superior MA focus that was isoelectric, and then positive in lead V_1.

PERINODAL REGION AND INTERATRIAL SEPTUM. An isoelectric P-wave in lead V_1 was associated with a specificity

and a PPV of 100% and an NPV of 97% for perinodal and right septal tachycardias, but the sensitivity was only 50% (Table 3).

A negative, then positive P-wave in V_1 was present in 3 of 3 left septal tachycardias and in 1 of 7 perinodal tachycardias. In the remaining ECG leads, there was significant overlap in PWM between perinodal and left septal sites.

P-wave algorithm. Based on the information presented in Tables 1 to 3, a P-wave algorithm was developed to allow prospective identification of the likely site of origin of a tachycardia according to PWM (Fig. 6).

PROSPECTIVE APPLICATION OF THE P-WAVE ALGORITHM. This algorithm was subsequently prospectively applied to a new population of 30 consecutive patients with focal AT. Tachycardia locations for these 30 patients were: CT (n = 11); TA (n = 5); CS ostium (n = 3); RAA (n = 3); perinodal (n = 1); MA (n = 2); RSPV (n = 1); LSPV (n = 1); LIPV (n = 1); LAA (n = 1); and left septum (n = 1). The correct site of tachycardia origin (or 1 of 2 neighboring structures) was determined in 28 of 30 and 28 of 30 tachycardias, respectively (93%). For both observers, the algorithm incorrectly suggested a CS ostium location for a tachycardia originating on the TA immediately adjacent to the CS ostium and a LPV location for a tachycardia at the RSPV.

DISCUSSION

This study describes the PWM from a large consecutive group of patients with focal AT who underwent RFA. In this large series, we have observed that focal AT does have a particular anatomic distribution, as previously described (1,4–7). Importantly, we have shown that these anatomic locations have a signature PWM that provides a reasonably high predictive accuracy. Sites that demonstrated overlap in morphology were those in close anatomic proximity. In particular, these included the CT and RSPV, the left and right septal regions, and the LAA and LSPV.

Using the characteristic P-wave patterns, we were able to develop an algorithm to predict the likely anatomic site of tachycardia origin. The algorithm was then prospectively evaluated in an additional 30 patients and found to have a positive predictive accuracy of 93%. Until now, there has been no unifying attempt to match PWM to the particular anatomic locations from which ATs tend to arise and thereby develop an algorithm that may be applied prospectively.

RA versus LA foci. An important question to be addressed in an analysis of tachycardia PWM is the likely atrium of origin. In the current study of 130 tachycardia P waves, ECG lead V_1 was the most useful in distinguishing a right from a left atrial focus. A negative or biphasic (positive, then negative) P-wave in lead V_1 was associated with a 100% specificity and PPV for a tachycardia arising from the RA. A positive or biphasic (negative, then positive) P-wave in ECG lead V_1 was associated with a 100% sensitivity and NPV for tachycardia originating in the LA. Lead V_1 is located to the right and anteriorly in relation to the atria, which should be considered as right anterior and left posterior. Thus, for example, tachycardias originating from the tricuspid annulus were negative in V_1 because of the anterior and rightward location of this structure. The P-wave in V_1 is universally positive for tachycardias originating at the PVs, because of the posterior location of these structures.

Tang et al. (10) provided a detailed analysis of the utility of P-wave configuration in distinguishing right from left atrial tachycardia. In 31 patients, the most useful leads for distinguishing right from left atrial foci were V_1 and aVL. The major limitation in the use of a positive P-wave in lead V_1 to predict left atrial origin was in distinguishing foci at

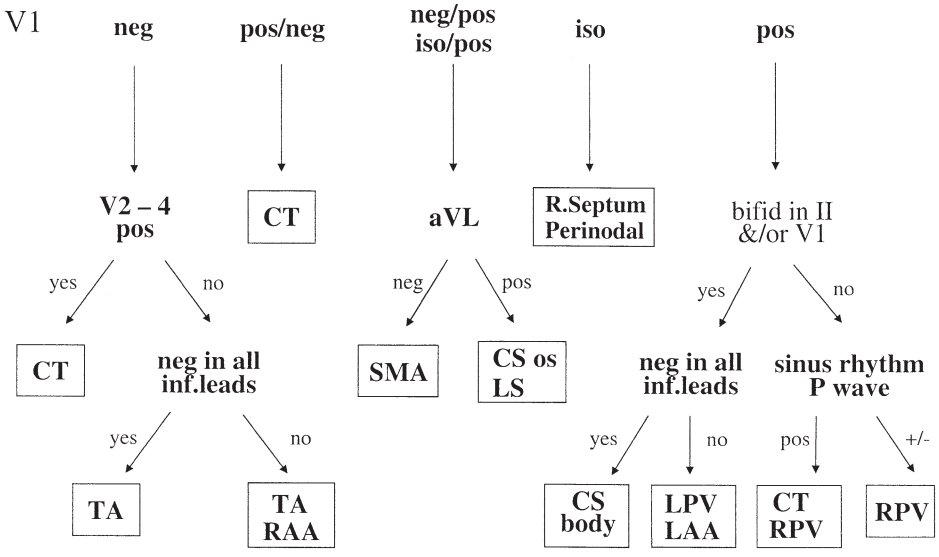

Figure 6. A P-wave algorithm constructed on the basis of findings from 130 atrial tachycardias correctly localized the focus in 93%. Abbreviations as in Figure 1.

the superior CT from the RSPV. This is an important consideration given the relatively common occurrence of AT from both sites, which are known to be in close anatomic proximity. Tang et al. (10) made the important observation that RSPV foci showed a change in configuration from biphasic in SR to upright in AT, a change not observed for right-sided tachycardias. In the current study, a biphasic P-wave in SR becoming upright in tachycardia was observed in 9 of 14 RSPV tachycardias, but not in any cristal tachycardias. Although not described in the present study, foci arising from the superior vena cava (SVC), a neighboring anatomic structure, also produce a biphasic or upright P-wave in lead V_1 (11).

The predictive value of PWM for localizing the atrium of origin was more limited when tachycardia foci arose from the interatrial septum. Prior studies have also demonstrated that tachycardias arising from the interatrial septum are associated with variable PWM with considerable overlap for tachycardias located on the left and right side of the septum (8,12,13). Indeed, the known spatial limitations of P-wave analysis are highlighted when considering ATs that arise from the interatrial septum, and this at least in part contributes to the variable P-wave observations (14).

In an elegant study of focal AT using noncontact mapping, Higa et al. (3) described a preferential direction of activation and an atrial breakout point in the majority related to the anisotropic properties of the CT. Although an initial pathway of preferential conduction may potentially alter the PWM, the small differences in distance between successful ablation at the focus compared to the atrial break-out appear not to have a significant effect on PWM, perhaps because of the spatial resolution of the P-wave.

Study limitations. In keeping with the known spatial limitations of PWM, anatomic sites that were in close proximity, such as the high crista and RSPV and ostium of CS and left septum, could not always be separated. Knowledge of these overlapping sites is nonetheless important to the clinical electrophysiologist. The findings in the present study do not apply to tachycardias following extensive atrial linear ablation or patients with congenital heart disease or extensive scarring where atrial activation is frequently substantially altered. This series does not include uncommon but potential sites of focal AT such as the SVC and ligament of Marshall. Although the patient number for the prospective application of the P-wave algorithm is smaller than the total series, we believe this compares very favorably with prior publications (1,3,8,11,13).

Conclusions. P-wave morphology provides a useful guide to the localization of focal AT. Electrocardiographic lead V_1 was the most useful in identifying the likely anatomic site of origin for focal AT. A characteristic PWM was able to identify common anatomic locations with high sensitivity and specificity. A P-wave algorithm was constructed and prospectively identified the focus in 93%.

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