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Diagnostic Value of Tachycardia Features and Pacing Maneuvers During Paroxysmal Supraventricular Tachycardia

Bradley P. Knight, MD, FACC, Matthew Ebinger, DO, Hakan Oral, MD, Michael H. Kim, MD, Christian Sticherling, MD, Frank Pelosi, MD, Gregory F. Michaud, MD, S. Adam Strickberger, MD, FACC, Fred Morady, MD, FACC

Ann Arbor, Michigan

OBJECTIVES The purpose of this prospective study was to quantitate the diagnostic value of several tachycardia features and pacing maneuvers in patients with paroxysmal supraventricular tachycardia (PSVT) in the electrophysiology laboratory.

BACKGROUND No study has prospectively compared the value of multiple diagnostic tools in a large group of patients with PSVT.

METHODS One hundred ninety-six consecutive patients who had 200 inducible sustained PSVTs during an electrophysiology procedure were included. The diagnostic values of four baseline electrophysiologic parameters, nine tachycardia features and five diagnostic pacing maneuvers were quantified.

RESULTS The only tachycardia characteristic that was diagnostic of atrioventricular (AV) nodal reentry was a septal ventriculoatrial (VA) time of <70 ms, and no pacing maneuver was diagnostic for AV nodal reentry. An increase in the VA interval with the development of a bundle branch block was the only tachycardia characteristic that was diagnostic for orthodromic tachycardia, but it occurred in only 7% of all tachycardias. An atrial-atrial-ventricular response upon cessation of ventricular overdrive pacing was diagnostic of atrial tachycardia, and this maneuver could be applied to 78% of all tachycardias. Burst ventricular pacing excluded atrial tachycardia when the tachycardia terminated without depolarization of the atrium, but the result could be obtained only in 27% of patients.

CONCLUSIONS This prospective study quantitates the diagnostic value of multiple observations and pacing maneuvers that are commonly used during PSVT in the electrophysiology laboratory. The findings demonstrate that diagnostic techniques rarely provide a diagnosis when used individually. Therefore, careful observations and multiple pacing maneuvers are often required for an accurate diagnosis during PSVT. The results of this study provide a useful reference with which new diagnostic techniques can be compared. (J Am Coll Cardiol 2000; 36:574–82) © 2000 by the American College of Cardiology

Several tachycardia features and diagnostic pacing maneuvers have been proposed to differentiate the various forms of paroxysmal supraventricular tachycardia (PSVT) in the electrophysiology laboratory (1–11). The usefulness of some, but not all, of these diagnostic techniques has been studied individually (5–10). However, no study has prospectively compared the value of multiple diagnostic tools. The purpose of this prospective study was to quantitate the diagnostic usefulness of several tachycardia features and pacing maneuvers commonly used in the electrophysiology laboratory in a large group of consecutive patients with PSVT.

METHODS

Study design. Patients who had inducible PSVT during an electrophysiology procedure were included in this study. Baseline electrophysiologic parameters and tachycardia features were characterized. After tachycardia was induced, prospectively defined diagnostic pacing maneuvers were performed and the response to each maneuver was recorded. After the tachycardia diagnosis was established, the prevalence, sensitivity, specificity and predictive values of each diagnostic technique were calculated.

Characteristics of subjects. The study population consisted of 196 consecutive patients with inducible sustained PSVT. Their mean age was 46 ± 16 years (range 14 to 85 years), and 67% were women. A majority of patients (85%) had no evidence of structural heart disease. The remaining patients had coronary artery disease (n = 10), hypertension (n = 10), nonischemic dilated cardiomyopathy (n = 4), aortic valve disease (n = 3), hypertrophic cardiomyopathy (n = 1), previous atrial septal defect repair (n = 1) or previous ventricular septal defect repair (n = 1).

Electrophysiologic procedure. Electrophysiology procedures were performed using standard techniques (10). Antiarrhythmic drug therapy was discontinued for at least five half-lives. In the first 100 patients, recordings of four electrocardiographic (ECG) leads and three intracardiac electrograms were made on paper at a speed of 100 mm/s using a Mingograph 7 recorder (Siemens-Elema, Solna, Sweden). The intracardiac electrograms were filtered at 40

From the Department of Internal Medicine, Division of Cardiology, University of Michigan Health System, Ann Arbor, Michigan.
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Abbreviations and Acronyms

AH	= atrial His bundle
AV	= atrioventricular
ECG	= electrocardiogram, electrocardiographic
PSVT	= paroxysmal supraventricular tachycardia
VA	= ventriculoatrial

and 500 Hz. The recordings also were digitized and stored on optical disks (Quinton Electrophysiology, Seattle, Washington). In the remaining 96 patients, digital recordings of 12 ECG leads and five intracardiac electrograms were displayed and stored on optical disk using the EP Workmate recording system (EP Medical Systems, Mt. Arlington, New Jersey). The intracardiac electrograms were filtered at 30 and 500 Hz and displayed with amplifier settings of ±0.5 to ±1.0 mV.

Overdrive atrial and ventricular pacing and premature extrastimuli were used to induce supraventricular tachycardia. Intravenous isoproterenol was administered if tachycardia was not inducible or was nonsustained at baseline (12).

Diagnostic tachycardia features. Four baseline observations and nine tachycardia features were prospectively chosen for evaluation and are summarized in Table 1. Dual atrioventricular (AV) nodal physiology was defined as an increase of ≥50 ms in the A2H2 interval with atrial extrastimuli decremented in 10-ms steps. Para-Hisian pacing was performed by overdrive pacing at the site of the largest His bundle recording with various stimulation intensities to achieve simultaneous ventricular and His bundle capture as well as ventricular capture alone. The response was considered extranodal when the retrograde atrial activation timing during His bundle capture was the same as during ventricular capture without His bundle capture (8).

Diagnostic pacing maneuvers. Five diagnostic pacing maneuvers were prospectively chosen for evaluation in this study (Table 2). Each maneuver was intended to elicit a response that was either diagnostic or provided supportive evidence for a tachycardia mechanism. After tachycardia was induced, as many pacing maneuvers were performed as possible depending on the ability to reproducibly induce the tachycardia. Maneuvers were performed in an order that was felt to be helpful clinically, but not all tachycardias were reproducibly inducible. Therefore, not all maneuvers were performed during some tachycardias. The response to each maneuver was recorded. The term "entrainment" was used in this study to refer to acceleration of the atrial and ventricular electrograms to the pacing cycle length during overdrive pacing from the atrium or ventricle, with resumption of the original cycle length upon cessation of pacing.

The first pacing maneuver was to overdrive pace the high right atrium transiently during tachycardia at a cycle length just below the tachycardia cycle length. If the tachycardia terminated, tachycardia was reinduced and the maneuver was repeated. If the tachycardia continued upon cessation of pacing, the ventriculoatrial (VA) interval of the return cycle was categorized as fixed if the interval was within 10 ms of the VA interval during tachycardia. Otherwise, the interval was considered variable. A fixed VA interval would be expected to occur in AV nodal reentry or orthodromic reciprocating tachycardia because the timing of atrial activation is dependent on ventricular activation (Fig. 1). A variable interval suggests that the tachycardia is atrial (5).

The second maneuver was to overdrive-pace the right atrium repeatedly during tachycardia at the longest cycle length that resulted in AV block. The last atrial His bundle (AH) interval upon cessation of pacing was evaluated. If termination of the tachycardia was associated with an AH interval that was relatively short compared with the AH intervals that resulted in continuation of tachycardia, tachycardia termination was considered to be dependent on the last AH interval (5). Termination of atrial tachycardia would not be expected to be dependent on the AH interval.

The third pacing maneuver was to overdrive-pace the right ventricle transiently during tachycardia at a cycle length just shorter than the tachycardia cycle length. Among patients in whom overdrive pacing did not result in acceleration of the atrial rate to the pacing rate, the reason was either because the VA block cycle length during tachycardia was greater than the tachycardia cycle length or because the tachycardia always terminated during ventricular pacing. If ventricular pacing terminated the tachycardia, the tachycardia was reinduced and the maneuver was repeated. When entrainment of the atrium during the tachycardia with ventricular pacing was possible, the atrial activation sequence was categorized as either the same or different compared with the activation sequence during tachycardia. A different activation sequence would be consistent with an atrial tachycardia or a bystander accessory pathway. Also, when entrainment was possible, the electrogram sequence immediately after the last paced ventricular complex was categorized as "atrial-ventricular" (A-V) or "atrial-atrial-ventricular" (A-A-V). An A-A-V response is consistent with an atrial tachycardia and an A-V response is consistent

Table 1. Baseline Observations and Tachycardia Features Prospectively Selected for Evaluation

Baseline Observations and Tachycardia Features
Baseline Observations
1. Ventricular preexcitation during sinus rhythm
2. Dual AV nodal physiology
3. VA block cycle length >600 ms at baseline
4. Extranodal response to Para-Hisian pacing during sinus rhythm
Tachycardia Features
1. Induction dependent on a critical AH interval
2. Isoproterenol required to sustain tachycardia
3. Tachycardia cycle length ≥500 ms
4. Septal VA interval >70 ms
5. Eccentric atrial activation
6. Spontaneous AV block during tachycardia
7. Spontaneous termination with AV block
8. Development of bundle branch block
9. Effect of bundle branch block on VA conduction time

AH = atrial His bundle; AV = atrioventricular; VA = ventriculoatrial.

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Table 2. Five Prospectively Identified Diagnostic Pacing Maneuvers and Questions Asked

Pacing Maneuver	Questions Asked
1. Pace the atrium during SVT at a CL 10–40 ms < SVT CL	• Is VA interval with return beat the same as during SVT?
2. Pace the atrium during SVT at AV Block CL	• Is SVT termination dependent on last AH interval?
3. Pace the ventricle during SVT at a CL 10–40 ms < SVT CL	• Can the atrial rate be accelerated to the ventricular pacing rate? • If the atrial rate cannot be accelerated to the ventricular pacing rate, is it because the SVT always terminates or because the VA block CL during SVT > SVT CL? • If the atrial rate can be accelerated to ventricular pacing rate, is the response upon cessation of pacing "A-A-V" or "A-V"? • If the atrial rate can be accelerated to ventricular pacing rate, is the atrial activation the same as during SVT?
4. Pace ventricle during SVT at a CL 200–250 ms for 3–6 beats	• Can SVT be terminated by burst ventricular pacing without depolarization of the atrium?
5. Scan diastole with a premature ventricular stimulus	• Can SVT be terminated with a ventricular extrastimulus during His-bundle refractoriness? • Can SVT be terminated with a ventricular extrastimulus without affecting the atrium?

A-A-V = atrial-atrial-ventricular; A-V = atrial-ventricular; AV = atrioventricular; CL = cycle length; SVT = supraventricular tachycardia; VA = ventriculoatrial.

with AV nodal reentry or orthodromic AV reentrant tachycardia (10).

The fourth pacing maneuver was to burst-pace the right ventricle for three to six beats during tachycardia at a cycle length of 200 ms to 250 ms. This was repeated until the maneuver resulted in tachycardia termination or until at least three attempts had been made. If the ventricle was dissociated from the tachycardia and termination did not occur, orthodromic reentrant tachycardia was excluded. If termination occurred during ventricular pacing, it was determined whether or not the atrium had been depolarized. Tachycardia termination without depolarization of the atrium excludes atrial tachycardia (Fig. 2).

The fifth pacing maneuver was to scan diastole with a ventricular extrastimulus from the right ventricular apex during tachycardia. The responses that were evaluated included whether or not tachycardia termination occurred, whether or not the His bundle was refractory when termination occurred, and whether or not the atrium was depolarized when termination occurred. Atrial depolarization or tachycardia termination with a ventricular extrastimulus delivered during His bundle refractoriness during tachycardia is consistent with the presence of an accessory AV connection.

Diagnosis of tachycardia mechanism. Tachycardia diagnoses were made based on standard criteria (1–11) and the results of ablation. A diagnosis of each tachycardia was made with certainty. An atrial activation sequence that was not compatible with retrograde conduction through the AV junction excluded AV nodal reentry. Atrial tachycardia was

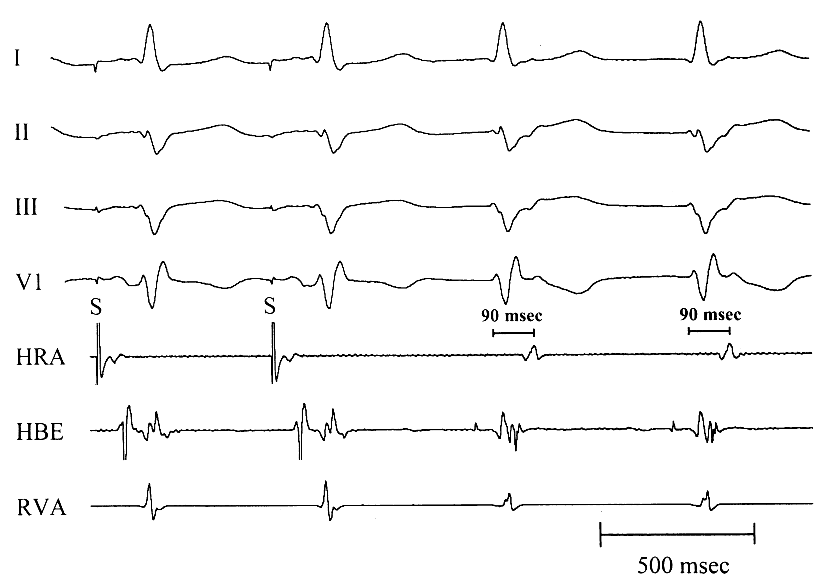

Figure 1. Example of the first diagnostic pacing maneuver. Shown are surface electrograms I, II, III, V1, and intracardiac recordings from the high right atrium (HRA), His-bundle electrogram (HBE), and right ventricular apex (RVA). The tachycardia is entrained with atrial pacing. The VA interval of the return beat is the same as the VA interval of the tachycardia. This observation, referred to as "VA linking," would not be expected during atrial tachycardia because atrial activation is not dependent on ventricular activation. S = stimulus.

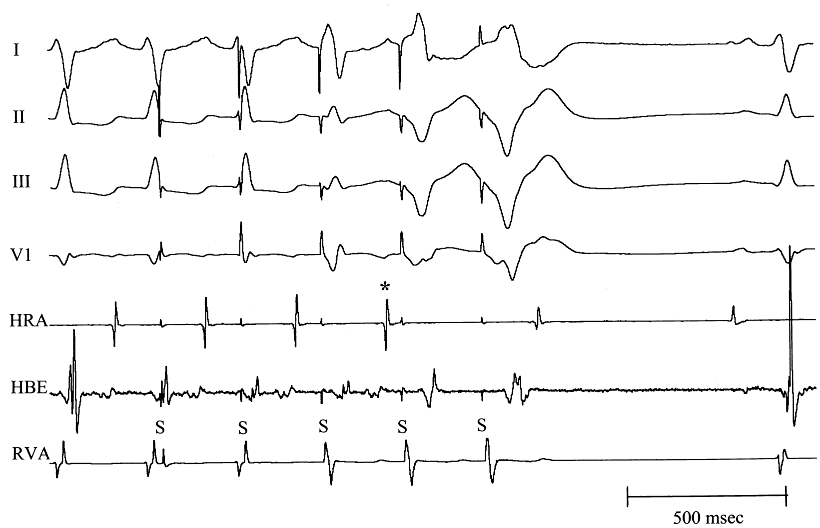

Figure 2. Example of the fourth diagnostic pacing maneuver. The format is the same as Figure 1. A burst of ventricular pacing is delivered during tachycardia. The tachycardia terminates without depolarization of the atrium. The last beat of the tachycardia is denoted with an asterisk. This observation excludes atrial tachycardia. S = stimulus.

excluded if ventricular pacing or a ventricular extrastimulus terminated the tachycardia without depolarizing the atrium, or when the VA conduction interval changed with the development of bundle-branch block aberration. Findings considered diagnostic for orthodromic reciprocating tachycardia included an increase in the VA conduction interval with the development of bundle-branch block. Orthodromic reciprocating tachycardia was excluded if tachycardia persisted during AV block. Atrioventricular nodal reentry was considered typical if the septal VA interval was ≤70 ms and atypical if the interval was >70 ms.

Radiofrequency ablation of each tachycardia was attempted, except for eight of the 25 atrial tachycardias (three patients had a left atrial tachycardia and were rescheduled for a transeptal procedure, and five patients had an atrial tachycardia that could not be mapped, because the tachycardia was not reproducibly sustainable). Ablation was successful in 98% of AV nodal reentrant tachycardias, 95% of orthodromic reciprocating tachycardia, and 82% of atrial tachycardias.

Data analysis. Continuous variables are expressed as mean ± SD and were compared using the Student *t*-test and analysis of variance. Nominal variables were compared by chi-square analysis. Logistic regression was used to determine whether the predictive value of left bundle-branch aberration for orthodromic tachycardia was independent of the tachycardia rate. A p value of <0.05 was considered significant.

The sensitivity, specificity, positive predictive value and negative predictive values of each observation and maneuver were determined. Predictive values of each finding depend on the overall distribution of AV nodal reentry, orthodromic reciprocating and atrial tachycardias. However, in this study, not all five pacing maneuvers were performed during each tachycardia. If the distribution of tachycardias tested with one of the maneuvers differed from the overall distribution of tachycardias, then the predictive values of that maneuver would be inaccurate. For example, if only 1% of the tachycardias tested with the fifth maneuver (scanning diastole with a ventricular extrastimulus) were orthodromic reciprocating tachycardias, then no finding would have a high positive predictive value for orthodromic reciprocating tachycardia. Therefore, the predictive values were calculated as though each maneuver had been performed in every patient.

RESULTS

Tachycardia diagnoses. The tachycardia diagnoses, mean tachycardia cycle lengths and mean septal VA intervals are summarized in Table 3.

Value of baseline observations and tachycardia features. The prevalence, sensitivity, specificity, positive predictive value and negative predictive values of each baseline observation and tachycardia feature are summarized in Table 4.

The only characteristic that was diagnostic of AV nodal reentry was a septal VA time of ≤70 ms. There were no atrial tachycardias in this study with a septal VA time of ≤70 ms. Characteristics that were strongly predictive of AV nodal reentry were dual AV nodal physiology, induction dependent on a critical AH interval, and concentric activation. Eccentric atrial activation excluded AV nodal reentry and occurred in 31% of tachycardias. An increase in the VA interval >20 ms with a bundle-branch block aberration also excluded AV nodal reentry and occurred in 7% of tachycardias.

An increase in the VA interval with the development of a bundle-branch block was the only tachycardia feature that was diagnostic for orthodromic tachycardia. Ventricular preexcitation had positive predictive value of 86%. Other

Table 3. Supraventricular Tachycardia Characteristics

	Tachycardia Diagnosis					
	AVNRT					
	Overall	Typical*	Atypical**	ORT	AT	p Value
Number (%)	113 (57%)	102 (51%)	11 (6%)	62 (31%)	25 (13%)	NA
Cycle Length (ms)	333 ± 71	329 ± 71	363 ± 63	338 ± 56	361 ± 66	0.17
Septal VA Interval (ms)	55 ± 47	43 ± 28	162 ± 55	157 ± 58	214 ± 70	<0.001

*VA interval ≤70 ms ("slow-fast").
**VA interval >70 ms ("slow-slow" or "fast-slow").
AT = atrial tachycardia; AVNRT = atrioventricular nodal reentry; ORT = orthodromic reciprocating tachycardia; VA = ventriculoatrial.

characteristics that had a high positive predictive value but were not diagnostic for orthodromic tachycardia were an extranodal response with para-Hisian pacing and the development of a left bundle-branch block with tachycardia. A septal VA interval of ≤70 ms and spontaneous AV block during tachycardia excluded orthodromic reciprocating tachycardia. Absence of VA conduction at baseline was rare among patients with orthodromic reciprocating tachycardia but did not completely exclude the diagnosis.

No tachycardia feature had a significant positive predictive value for atrial tachycardia. Although more patients with atrial tachycardia developed AV block during tachycardia compared with patients with AV nodal reentry, when AV block occurred during tachycardia, the tachycardia was more likely to be AV nodal reentry because atrial tachycardia was much less common than AV nodal reentry (13). Spontaneous termination of tachycardia with AV block excluded atrial tachycardia but occurred in only 28% of tachycardias. There were no cases of atrial tachycardia in this study with a septal VA interval that was ≤70 ms or that demonstrated an extranodal response to para-Hisian pacing. Inductions that appeared dependent on a critical AH interval did not entirely exclude atrial tachycardia.

Value of diagnostic pacing maneuvers during PSVT. No diagnostic pacing maneuver confirmed a diagnosis of AV nodal reentry, but some maneuvers were able to exclude the diagnosis (Table 5). When the termination appeared dependent on a short AH interval during atrial pacing, there was still a 30% likelihood of orthodromic reciprocating tachycardia. Findings from maneuvers that excluded AV nodal reentry included a different atrial activation during entrainment from the ventricle as during tachycardia, an A-A-V response upon cessation of entrainment from the ventricle, and termination of the tachycardia with a ventricular extrastimulus when the His bundle was refractory.

Pacing maneuvers were occasionally able to completely rule in or rule out orthodromic reentrant tachycardia, but these findings were uncommon. Termination of the tachycardia with a ventricular extrastimulus when the His bundle was refractory without affecting atrial depolarization was diagnostic of orthodromic reciprocating tachycardia, but it occurred only in 10% of tachycardias. When the tachycardia could be entrained with ventricular pacing, a different atrial activation sequence during entrainment from the ventricle than during tachycardia and an A-A-V response upon cessation of entrainment from the ventricle excluded a diagnosis of orthodromic reciprocating tachycardia. The inability to entrain the atrium during the tachycardia with ventricular pacing because the VA block cycle length was greater than the tachycardia cycle length, and a dissociation of the ventricle from the tachycardia with pacing also excluded orthodromic reciprocating tachycardia.

An A-A-V response upon cessation of ventricular pacing and an atrial activation sequence during entrainment from the ventricle that was different than during tachycardia were diagnostic of atrial tachycardia. The inability to entrain the atrium during the tachycardia with ventricular pacing because the VA block cycle length was greater than the tachycardia cycle length had an 80% positive predictive value for atrial tachycardia. Any effect with a ventricular extrastimulus when the His bundle was refractory, including tachycardia termination and/or atrial preexcitation, excluded atrial tachycardia. Atrial tachycardias required isoproterenol for induction more often than AV nodal reentry and orthodromic reciprocating tachycardia, but the predictive value was poor.

Value of combinations of observations and maneuvers during PSVT. Because multiple clues are used to determine a diagnosis in the electrophysiology laboratory, the value of combinations of observations and maneuvers was determined. Although no simple algorithm could be devised that would quickly lead to a diagnosis for each tachycardia, a valuable and efficient approach was identified. The combination of two tachycardia observations (the septal VA interval and the retrograde atrial activation sequence) and one pacing maneuver (the response immediately after entrainment from the ventricle) provided a diagnosis in 65% of the tachycardias. If the septal VA interval is ≤70 ms and the response after entrainment from the ventricle is A-V, then the diagnosis is AV nodal reentry (found in 41% of tachycardias). If the septal VA interval is >70 ms, atrial activation is eccentric, and the response after entrainment from the ventricle is A-V, then the diagnosis is orthodromic tachycardia (found in 19% of tachycardias). If the response after entrainment from the ventricle is A-A-V, then the tachycardia is atrial (found in 5% of tachycardias). Other combinations of the results of these two observations and one pacing maneuver were not diagnostic, but they excluded

Table 4. Prevalence and Diagnostic Value of Baseline Observations and Tachycardia Features

Baseline Observations and Tachycardia Features	Prevalence (%)	Sensitivity (%)			Specificity (%)			PPV (%)			NPV (%)		
		ANVRT	ORT	AT	ANVRT	ORT	AT	ANVRT	ORT	AT	ANVRT	ORT	AT
Baseline Observations													
● Preexcitation present during sinus rhythm	15	3	41	4	69	97	83	10	86	3	46	78	86
● Dual AV nodal physiology	55	86	10	36	83	24	42	86	6	8	82	36	82
● VA block cycle length >600 ms at baseline	11	8	2	50	84	84	84	41	5	55	41	66	93
● Extranodal response to para-Hisian pacing	18	5	47	0	67	96	80	17	83	0	36	80	85
Tachycardia Features													
● Induction dependent on a critical AH interval	55	90	16	4	88	26	36	91	8	1	87	42	71
● Isoproterenol required to sustain tachycardia	39	47	23	57	68	51	62	65	18	17	56	58	91
● Tachycardia cycle length ≥500 ms	3	4	2	0	99	96	97	83	17	0	44	69	87
● Septal VA interval >70 ms	53	16	100	100	0	69	54	17	59	24	0	100	100
● Eccentric atrial activation	31	0	74	61	30	89	74	0	76	24	19	88	93
● Spontaneous AV block during tachycardia	10	11	0	33	91	85	93	60	0	40	44	65	91
● Spontaneous termination with AV block	28	33	31	0	78	73	67	66	34	0	48	70	82
● Development of RBBB	32	31	36	30	66	69	67	54	35	11	42	71	82
● Development of LBBB	12	1	36	4	73	99	87	4	92	4	36	81	87
● Increase in VA interval >20 ms with BBB	7	0	35	0	69	100	80	0	100	0	51	57	92

AH = atrial His bundle; AT = atrial tachycardia; AVNRT = atrioventricular nodal reentry; BBB = bundle branch block; CL = cycle length; LBBB = left bundle branch block; NPV = negative predictive value; PPV = positive predictive value; ORT = orthodromic reciprocating tachycardia; RBBB = right bundle branch block; SVT = supraventricular tachycardia; VA = ventriculoatrial.

either AV nodal reentry, orthodromic tachycardia or atrial tachycardia in 79% of the remaining tachycardias.

DISCUSSION

Main findings. The main findings of this study are that several observations made during sinus rhythm, tachycardia features and diagnostic pacing maneuvers can be used to differentiate the various forms of PSVT in the electrophysiology laboratory. However, it is uncommon that a tachycardia mechanism can be determined on the basis of an individual finding; tachycardia diagnoses are often one of exclusion, and some pacing maneuvers cannot be applied in a significant number of tachycardias. Because atrial tachycardia is much less common than AV nodal reentry and orthodromic reciprocating tachycardia, many features that are more common during atrial tachycardia have a low positive predictive value for atrial tachycardia. The findings of this study support the use of careful observations and several pacing maneuvers during PSVT in the electrophysiology laboratory.

Predictive value of baseline measurements. The finding of dual AV nodal physiology in a patient with PSVT makes AV nodal reentry very likely (positive predictive value, 86%). However, 6% of patients with dual AV node physiology had orthodromic reciprocating tachycardia, and 8% had an atrial tachycardia. In addition, evidence of an accessory pathway did not guarantee that orthodromic reciprocating tachycardia was the tachycardia mechanism. Ten percent of patients with preexcitation had AV nodal reentry. Therefore, it must be remembered that dual AV nodal pathways and accessory pathways can be incidental findings.

The diagnostic value of para-Hisian pacing during sinus rhythm may be underestimated in this study. The technique is best used to identify a septal pathway, but it was evaluated in this study in patients with accessory pathways in all locations. The positive predictive value of an extranodal response was 100% for orthodromic reciprocating tachycardia among the 31 tachycardias with a VA interval between 80 and 120. This reinforces the benefit of diagnostic tools used in combination.

The absence of VA conduction at baseline did not entirely exclude the presence of an accessory pathway. There was still a 5% chance that the tachycardia was orthodromic reciprocating tachycardia when the VA block cycle length was >600 ms at baseline. The reason is that conduction through accessory pathways sometimes is catecholamine-dependent (14).

Usefulness of measurements made during and at the initiation of tachycardia. The induction of typical AV nodal reentry is dependent on antegrade block in the fast pathway and sufficient antegrade delay in the slow pathway to allow retrograde fast pathway conduction. In this study a critical AH interval was required in 96% of tachycardias of typical AV nodal reentry. However, induction of an atrial tachycardia occasionally occurs with atrial pacing only at a

Table 5. Diagnostic Value of Pacing Maneuvers during Supraventricular Tachycardia

Pacing Maneuver/Result	Percent of Tachycardias Maneuver Attempted	Percent Able to Entrain	Percent Frequency of Result	Sensitivity (%)			Specificity (%)			PPV (%)			NPV (%)		
				AVNRT	ORT	AT	AVNRT	ORT	AT	AVNRT	ORT	AT	AVNRT	ORT	AT
Pace the atrium at 10–40 ms <SVT CL to entrain ventricle	89	87													
Fixed VA interval			87	97	98	5	27	18	3	64	35	1	87	96	17
Pace the atrium at the AV block CL	69	NA													
Termination dependent on AH			80	96	76	8	44	20	11	69	30	1	88	65	47
Pace the ventricle at 10–40 ms <SVT CL to entrain atrium	97	78													
Atrial activation same as SVT			92	100	100	0	20	13	0	64	36	0	100	100	0
A-V response after pacing			94	100	100	0	14	89	0	63	37	0	100	100	0
VA block CL >SVT CL			7	3	0	48	86	89	98	20	0	80	41	66	93
Ventricular pacing CL 200–250 ms	91	NA													
Termination w/o affecting atrium			27	27	37	0	74	78	69	57	43	0	44	73	83
Ventricle dissociated from SVT			16	11	0	16	95	88	93	75	0	25	45	66	89
Ventricular extrastimulus during diastole	80	NA													
SVT terminates, atrium not affected, His bundle refractory			3	0	8	0	94	100	97	0	100	0	42	71	87
SVT terminates, atrium affected, His bundle refractory			10	0	27	0	80	100	92	0	100	0	38	75	86
SVT does not terminate, atrium affected, His bundle refractory			12	0	34	0	76	100	88	0	100	0	37	77	86

AT = atrial tachycardia; AVNRT = atrioventricular nodal reentry; AV = atrioventricular; CL = cycle length; NA = not applicable; NPV = negative predictive value; PPV = positive predictive value; ORT = orthodromic reciprocating tachycardia; SVT = supraventricular tachycardia; VA = ventriculoatrial.

cycle length that results in a long AH interval, and it may appear as if a critical AH is required. In addition, the induction of orthodromic reciprocating tachycardia requires a critical delay in the AV interval to allow retrograde recovery of the accessory pathway, and it may appear as though a critical AH interval is required. Therefore, whether or not the induction of tachycardia is dependent on a critical AH interval is not in itself sufficient to make a diagnosis.

Previous studies have found that orthodromic reciprocating tachycardia tends to be faster than AV nodal reentry (1). However, the mean rates of orthodromic reciprocating tachycardia and AV nodal reentry were not different in this study. By contrast, atrial tachycardias tended to have a slower mean rate than AV nodal-dependent tachycardias. However, the slowest tachycardias were AV nodal reentry and orthodromic reciprocating tachycardia. There were no atrial tachycardias in this study with a cycle length greater than 500 ms. Therefore, although relatively slow supraventricular tachycardias are uncommon, they are usually not atrial.

One of the first tachycardia features used to differentiate different types of PSVT was the VA interval (6). A value of 60 to 70 ms has been consistently found to discriminate orthodromic reciprocating tachycardia from AV nodal reentry (7). The results of this study confirm the value of the VA interval. No cases of orthodromic reciprocating tachycardia had a septal VA interval of $<$70 ms. In addition, there were no cases of atrial tachycardia with a short VA interval. Atrial tachycardia with a short VA interval is theoretically possible, but appears to be very uncommon.

Diagnostic value of spontaneous AV or bundle-branch block. The spontaneous development of AV or bundle-branch block is very useful diagnostically but uncommon. Although persistence of tachycardia during AV block excludes orthodromic reciprocating tachycardia, it occurs in only 10% of tachycardias. Furthermore, it is not helpful in discriminating AV nodal reentry from atrial tachycardia. In fact, the positive predictive value of persistent tachycardia in the face of AV block was higher for AV nodal reentry than for atrial tachycardia. Spontaneous termination with AV block excludes atrial tachycardia but occurs in only 28% of tachycardias.

A significant change in the VA interval with the development of bundle-branch block has long been known to be diagnostic of orthodromic reciprocating tachycardia and localizes the pathway to the same side as the block (9). Results of this study demonstrate that an increase in the VA interval of $>$20 ms is diagnostic of orthodromic reciprocating tachycardia, but it occurs in only 7% of patients with PSVT.

Interestingly, the mere development of left bundle-branch aberration with tachycardia is strongly predictive of orthodromic reciprocating tachycardia (92% positive predictive value) and is predictive of orthodromic reciprocating tachycardia independent of the tachycardia rate. Patients who developed a left bundle-branch block had a shorter tachycardia cycle length compared with those who did not, although the difference did not reach statistical significance (317 ± 54 vs. 340 ± 68 ms; $p = 0.12$). However, patients with orthodromic reciprocating tachycardia were 77 times more likely to develop a left bundle-branch block aberration than if they had AV nodal reentry, regardless of the tachycardia cycle length. Left bundle-branch block aberration occurred in 36% of patients with orthodromic reciprocating tachycardia, 1% with AV nodal reentry and 4% with atrial tachycardia ($p < 0.001$). Right bundle-branch block occurred in approximately one third of patients with each form of PSVT.

Two reasons have been proposed to explain why prolonged aberration occurs less commonly during AV nodal reentry than orthodromic reciprocating tachycardia (1). First, the induction of AV nodal reentry requires significant AV nodal delay, which makes the H1H2 interval longer and makes aberration unlikely. Second, left bundle-branch block facilitates induction of orthodromic reciprocating tachycardia when a left-sided accessory pathway is present. In this study, 19 of the 24 cases of orthodromic reciprocating tachycardia that developed left bundle-branch aberration had a left-sided accessory pathway.

Diagnostic value of pacing maneuvers. Atrial pacing maneuvers were most helpful by providing evidence against atrial tachycardia. Neither of the two atrial-based pacing maneuvers evaluated in this study were able to exclude atrial tachycardia completely. A VA interval with the first return beat after atrial pacing with 1:1 conduction that is the same as the VA interval during the tachycardia suggests that atrial activation is linked to ventricular activation and was expected to exclude atrial tachycardia. However, coincidental events can rarely result in apparent "VA linking" during atrial tachycardia. In addition, a VA interval with the first return beat that differs from the VA interval during tachycardia was not expected to be seen with AV nodal reentry, but it occurred in 3% of tachycardias. A recent study has also demonstrated variation in the VA interval at the induction of AV nodal reentry (15). Atrial pacing maneuvers were not helpful in differentiating AV nodal reentry from orthodromic reciprocating tachycardia.

The findings of this study confirm the value of ventricular-based pacing maneuvers during a narrow complex tachycardia. An A-V response upon cessation of pacing completely excluded the possibility of atrial tachycardia, and this maneuver could be applied to 78% of all tachycardias. In the remainder of tachycardias, when VA block occurred during attempts to entrain the tachycardia, there was an 80% likelihood that the tachycardia was atrial. The advantages of this maneuver have recently been described and include speed and persistence of the tachycardia after the maneuver is completed (10).

Burst ventricular pacing to terminate the tachycardia without depolarizing the atrium is commonly proposed as a helpful initial diagnostic maneuver. The maneuver can clearly exclude atrial tachycardia, but this result was obtained in only 27% of patients because the tachycardia usually terminates when the atrium is depolarized. The maneuver appears to be worthwhile when entrainment from the ventricle provides diagnostic findings. Twenty-five of the tachycardias could not be entrained from the ventricle, because the tachycardia would always terminate. When burst ventricular pacing was performed during these tachycardias, a useful finding was obtained in 62% (burst ventricular pacing resulted in dissociation of the ventricle in 31% and resulted in termination without depolarizing the atrium in 31% of the tachycardias).

Previous studies. A previous study systematically evaluated the diagnostic value of overdrive atrial and ventricular pacing in 53 patients with PSVT (5). This study was able to quantify the usefulness of diagnostic techniques identified in the previous study in a larger group of patients and to prospectively compare overdrive pacing to other diagnostic tools.

Study limitations. One limitation of this study is that some rare types of tachycardia were not represented in the study. Therefore, some findings that resulted in a 100% positive predictive value for a particular tachycardia mechanism may not be completely diagnostic. For example, termination of a tachycardia with a ventricular extrastimulus when the His bundle is refractory without depolarizing the atrium is not diagnostic of orthodromic reciprocating tachycardia using an accessory AV connection, because it is possible that the tachycardia is using a concealed nodofascicular bypass tract.

Another limitation is that the predictive values may not apply to all electrophysiology laboratories. Our case mix was representative of the expected prevalence of AV nodal reentry, orthodromic reciprocating tachycardia and atrial tachycardia. However, the predictive values would differ in a laboratory that has a different referral pattern (for example, a laboratory that specializes in atrial tachycardia).

A third limitation is that some diagnostic maneuvers that have been described, such as the administration of adenosine (16) and carotid sinus pressure (17), were not tested in this study. However, the number of maneuvers performed had to be limited to allow completion during a clinically indicated electrophysiologic procedure.

The predictive value of some of the tachycardia observations may not apply to PSVTs that occur spontaneously. For example, the predictive value of left bundle-branch aberration may be poor when the tachycardia is not induced by pacing.

Clinical implications. Successful ablation of PSVT is dependent on an accurate diagnosis of the tachycardia mechanism. This prospective study quantitates the diagnostic value of multiple observations and pacing maneuvers that are commonly used during PSVT in the electrophysiology laboratory. The findings demonstrate that diagnostic techniques rarely provide a diagnosis when used individually. A combination of two tachycardia observations (the septal VA interval and the retrograde atrial activation sequence) and one pacing maneuver (the response immediately after entrainment from the ventricle) provided a diagnosis in 65% of the tachycardias and excluded a tachycardia mechanism in an additional 27% of tachycardias. Therefore, careful observations and multiple pacing maneuvers are often required for an accurate diagnosis during PSVT. The results of this study provide a useful reference with which new diagnostic techniques can be compared.

Reprint requests and correspondence: Dr. Bradley P. Knight, University of Michigan Health System, 1500 East Medical Center Drive/B1F245, Ann Arbor, Michigan 48109-0022. E-mail: bpk@umich.edu.

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