Validation of right ventricular pacing response during supraventricular tachycardia in mechanistic diagnosis (transition zone)

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Background
Right ventricular pacing (RVP) during supraventricular tachycardia (SVT) produces progressive QRS fusion before the QRS morphology becomes stable. This transition zone (TZ) may provide useful information for differentiating orthodromic reciprocating tachycardia (ORT) from atrioventricular nodal re-entrant tachycardia and atrial tachycardia independent of entrainment success.

Methods and results
We studied the effect of properly timed RVP on atrial timing during the TZ in 63 patients with SVT who had RVP within 40 ms of the tachycardia cycle length. The TZ during RVP includes progressively fused QRS complexes and the first paced complex with a stable QRS morphology based on analysis of the 12-lead ECG. We also measured the stimulus–atrial (SA) interval from the end of the TZ and with each QRS complex thereafter until pacing was terminated or ventriculoatrial block occurred. A fixed SA interval was defined as variation less than or equal to 10 ms during RVP. Atrial pre-excitation, postexcitation, or SVT termination with abrupt ventriculoatrial block was observed within the TZ in 19 of 22 patients with ORT. A fixed SA interval was established within the TZ in 22 of 22 patients with ORT. At least one of these two responses was observed in all patients with ORT. Only four patients out of 36 with atrioventricular nodal re-entrant tachycardia showed atrial pre-excitation within TZ and only four patients showed fixed SA within TZ. None of the atrial tachycardia patients had atrial timing perturbed or a fixed SA interval established within the TZ.

Conclusion
During RVP within 40 ms of the tachycardia cycle length, ORT is the likely mechanism when atrial timing is perturbed or a fixed SA interval is established within the TZ.

Keywords:
RV pacing, SVT, transition zone

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Introduction

Significant diagnostic information may be derived from right ventricular pacing (RVP) that results in entrainment of supraventricular tachycardia (SVT) [1]. An 'AAV' response after overdrive pacing suggests atrial tachycardia (AT), whereas an 'AV' response suggests an atrioventricular (AV) nodal-dependent SVT [2].

When differentiating atypical atrioventricular node re-entry (AVNRT) from orthodromic reciprocating tachycardia (ORT) using a septal accessory pathway, a stimulus–atrial (SA) minus ventriculoatrial (VA) interval less than or equal to 85 ms, a postpacing interval (PPI) minus tachycardia cycle length (TCL) of less than or equal to 115 ms, and entrainment with stable QRS fusion are highly specific for ORT [3].

However, repeated RVP attempts fail to achieve entrainment in 22% of patients with SVT. Instead, RVP may result in AV dissociation or tachycardia termination, preventing evaluation of the postpacing response [2,4].

Single ventricular extrastimuli can be scanned throughout the diastolic SVT cycle, and their effect on subsequent atrial timing can be measured to help differentiate among AVNRT, ORT, and AT [1]. This pacing technique does not rely on entrainment success. The diagnosis of ORT is suspected when a His refractory ventricular extrastimulus results in atrial pre-excitation and is confirmed when a His refractory ventricular extrastimulus results in atrial postexcitation or abrupt SVT termination without atrial activation [1,5].

Progressive QRS fusion is usually seen at the beginning of RVP and is the result of collision between the ventricular activation wavefront through the AV node and the pacing wavefront. Therefore, the significance of fusion QRS complexes is similar to scanned single ventricular extrastimuli delivered when the His bundle is refractory.

These fused QRS complexes are identified by a QRS morphology intermediate between native QRS complexes and the paced complex with a stable morphology. The influence of RVP during this 'transition zone' (TZ) on various forms of SVT has not been reported.

Patients and methods

Study design

We performed a retrospective and prospective study of the electrophysiologic response of various SVT mechanisms to right ventricular (RV) pacing delivered for the purpose of tachycardia entrainment.

Inclusion criteria

All patients with documented narrow complex SVT who presented to the electrophysiology lab., including all age and sex groups (in Assiut University cath. lab. and Cairo University cath.lab.), during the period between April 2015 and April 2016 were included in the study. The study included 63 patients. The study protocol was approved by the Ethical Committee of Assiut Faculty of Medicine.

Exclusion criteria

The exclusion criteria were as follows:
(1) Atrial flutter
(2) Atrial fibrillation
(3) Manifest pre-excitation on surface ECG.

All patients were subjected to the following:
(1) Written informed consent
(2) Complete history and examination
(3) Twelve-lead ECG during rest and another one with documented possible SVT
(4) The baseline electrophysiological study was conducted after antiarrhythmic drugs had been discontinued for at least five half-lives.

The study will include patients who presented with supraventricular tachyarrythmia (AVNRT, AVRT (Atrioventricular Reentry Tachycardia), and AT).

Electrophysiological procedure

The study was conducted under local anesthesia and mild sedation. Quadripolar electrode catheters were inserted through the femoral vein and positioned in the high right atrium, RV apex, and the anteroseptal tricuspid valve (His bundle recording).

A deflectable decapolar catheter was inserted into the femoral vein and positioned in the coronary sinus. All 12 ECG leads and intracardiac electrograms were recorded and stored on a digital recording system. Bipolar intracardiac electrograms were filtered between 30 and 500 kHz and recorded from the proximal electrode pair of quadripolar catheters and all pairs of decapolar catheters at speeds of 100–200 mm/s.

Bipolar pacing was performed from the distal electrode pair using a programmable stimulator (EP mate stimulator, St Jude Medical Inc, St Paul Minnesota, USA). The onset of RVP was timed to begin on the basis of sensing from the RV catheter, and thus the coupling interval between the last sensed RV signal and the first paced beat approximated the pacing cycle length (PCL).

5-supraventricular tachycardia diagnosis

The diagnosis of typical AVNRT was made when the VA interval in the earliest intracardiac atrial recording was less than 70 ms and one or more of the following criteria were satisfied:
(1) Presence of anterograde functional dual AV nodal pathways
(2) A concentric midline atrial activation sequence during SVT that matched that during RV pacing
(3) AV block coincident with tachycardia termination
(4) An 'AV' response after entrainment with RVP and PPI – TCL greater than 115 ms and SA – VA greater than 85 ms.

The diagnosis of atypical AVNRT was made when the earliest VA interval was greater than 70 ms and one or more of the following criteria were satisfied:
(1) Concentric atrial activation pattern
(2) An 'AV' response after entrainment with RVP and a PPI – TCL greater than 115 ms.

The diagnosis of ORT was made when the earliest VA interval was greater than 70 ms and one or more of the following criteria were satisfied:
(1) Eccentric atrial activation pattern
(2) An 'AV' response after entrainment with RVP with a PPI – TCL less than 115 ms and SA – VA less than 85 ms
(3) Atrial timing was advanced and tachycardia reset, atrial timing delayed, or tachycardia terminated without depolarizing the atrium associated with a scanned single premature ventricular extrastimulus that occurred when the His bundle was refractory (His synchronous single ventricular extrastimulus)

(4) The VA interval during tachycardia increased by greater than 20 ms with the development of ipsilateral bundle-branch block.

AT was diagnosed by the presence of an 'AAV' response after RVP, the absence of VA linking (i.e., variable AH and VA intervals), changes in H–H or V–V intervals that were preceded by changes in A–A intervals, or AV dissociation with rapid RVP at a cycle length between 200 and 250 ms during tachycardia.

Characteristics of right ventricular pacing trains and definitions

RVP was attempted from the RV apex. Entrainment was confirmed when the atrial cycle length accelerated to the PCL and the tachycardia resumed after pacing was discontinued.

Typically, RVP results in overdrive suppression when the atrial cycle length is accelerated to the paced cycle length in patients with focal AT, but we defined this as 'entrainment' in this study.

We reviewed the surface ECG for all patients included in this study. RVP trains were included in the analysis regardless of entrainment success if:

(1) PCL was 10–40 ms shorter than the TCL
(2) The maximum spontaneous oscillation in TCL within three cycles before the RVP train was less than 10 ms.

The TZ of RVP was defined as the region that contains paced complexes showing progressive QRS fusion and the first paced complex showing a stable QRS morphology. The end of the TZ, therefore, usually is a fully paced complex, but this complex may represent constant fusion in some patients with ORT.

All 12 ECG leads were inspected (by at least two independent observers) to determine the beginning and the end of the TZ in all patients. Atrial pre-excitation was defined as atrial cycle length shortening by greater than or equal to 15 ms during RVP. Atrial postexcitation was defined when atrial cycle length increased by greater than or equal to 15 ms. Termination without atrial depolarization was defined when SVT terminated with abrupt VA block during RVP.

The SA interval was measured at the end of the TZ, from the first paced complex showing a stable QRS morphology and for each subsequent QRS complex until pacing terminated or VA block occurred.

A fixed SA interval was defined as varying by less than 10 ms. For the purpose of measuring SA intervals, an RVP train that resulted in termination of tachycardia was included if:

(1) no change in atrial activation sequence was noted before SVT termination; and
(2) there were at least three paced QRS complexes with a stable morphology and VA conduction. When fusion beats resulted in termination of tachycardia during RVP train, SA interval was measured during other RVP trains in the same patient.

Tachycardia induction

If tachycardia is not induced in the baseline state, atropine or dobutamine was infused to facilitate its induction.

Statistical analysis

Data were collected and analyzed by computer program IBM SPSS (IBM Corp., Armonk, NY, USA), v. 20. Continuous data were expressed as mean ± SD and noncontinuous data were expressed as number (%). In addition, Student's *t*-test and χ^2-test were used to determine significance. Multinomial logistic regression was used for univariate and multivariate analysis.

Results

Baseline characteristics

A total of 63 patients with a history of paroxysmal SVT were included in the study. There were 36 patients with typical AVNRT, 22 patients with ORT, and five patients with AT. In the AVRT group, 11 (of 22, 50%) patients had left-lateral accessory pathways, six patients had septal accessory pathways, and five patients had right lateral accessory pathways. Baseline patient characteristics are shown in Tables 1 and 2.

Transition zone during right ventricular entrainment

Atrial timing perturbation in transition zone

In the AVNRT group, 32 (out of 36, 88.9%) patients did not show atrial timing perturbation in TZ with fixed A–A interval, but four patients showed atrial pre-excitation.

In the AVRT group, 19 (out of 22, 86.4%) patients showed atrial pre-excitation, and only three patients did not show atrial perturbation (three cases were left-lateral accessory pathway). None of the cases showed atrial postexcitation or termination of tachycardia during TZ.

In the AT group, three cases with successful entrainment did not show atrial timing perturbation within TZ (Figs 1–4).

Table 1 Baseline characteristics of study patients

				N (%)
Type of tachycardia				
AT				5 (7.9)
AVNRT				36 (57.1)
AVRT				22 (34.9)
Range of TCL (ms)				260-460
Mean±SD of TCL (ms)				332.1±42.6
	Type of tachycardia (*N* (%))			*P*
	AT	AVNRT	AVRT	
Age (years)				
<20	2 (40.0)	2 (5.6)	6 (27.3)	0.020*
20-40	1 (20.0)	11 (30.6)	12 (54.5)	
40-60	2 (40.0)	22 (61.1)	4 (18.2)	
>60	0 (0.0)	1 (2.8)	0 (0.0)	
Sex				
Male	2 (40.0)	16 (44.4)	8 (36.4)	0.830
Female	3 (60.0)	20 (55.6)	14 (63.6)	
RV entrainment	2 (40.0)	36 (100.0)	22 (100.0)	0.000
AV dissociation	3 (60.0)	0 (0.0)	0 (0.0)	

Significance of *is >>significant. AT, atrial tachycardia; AV, atrioventricular; AVNRT, atrioventricular node re-entry; RV, right ventricular; TCL, tachycardia cycle length.

Table 2 Responses to right ventricular pacing trains within 40 ms of the tachycardia cycle length in all types of supraventricular tachycardia

	Type of tachycardia (*N* (%))			*P*
	AT	AVNRT	AVRT	
A-A interval				
Not perturbed	0 (0.00)	32 (88.9)	3 (13.6)	0.000**
Pre-excited	0 (0.00)	4 (11.1)	19 (86.4)	
SA within TZ				
Fixed	0 (0.00)	4 (11.1)	22 (100.0)	0.000**
Not fixed	0 (0.00)	32 (88.9)	0 (0.00)	

Significance of **is very significant. AT, atrial tachycardia; AVNRT, atrioventricular node re-entry; SA, stimulus–atrial; TZ, transition zone.

Fixed stimulus–atrial interval established within transition zone

In the AVNRT group, 32 (of 36, 88.9%) patients did not show fixed SA interval, but only 4 patients showed fixed SA interval within TZ.

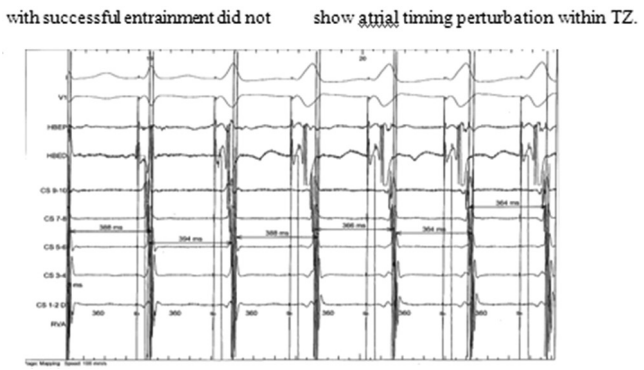
In the AVRT group, 22 (of 22, 100%) patients showed fixed SA interval within TZ.

In the AT group, three cases with successful entrainment did not show fixed SA interval (Figs 5 and 6).

Discussion

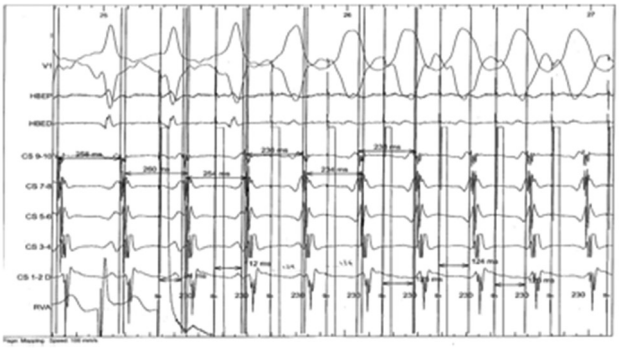
The main study finding was that all patients with ORT had either atrial timing perturbed (86.4%) or a fixed SA interval (100%) established within the TZ when pacing the RV within 40 ms of the TCL. These findings are independent of entrainment success. In patients with AT, AV dissociation or VAAV response on termination of entrainment was present during RVP. In the AVNRT group, most patients did not show atrial perturbation (88.9%), nor fixed SA interval (88.9%); only three patients (of 36) showed both atrial perturbation and fixed SA interval within TZ, and in two of them this occurred in the first beat with stable morphology. One case showed atrial pre-excitation without fixed SA (this also occurred in the first beat with stable morphology).

Figure 1



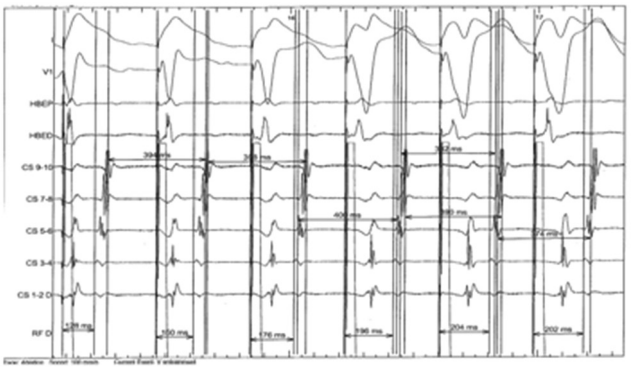
Case 1: Atrioventricular node re-entry with no atrial perturbation within transition zone.

Figure 2



Case 2: Atrioventricular node re-entry with atrial pre-excitation within transition zone.

Figure 3

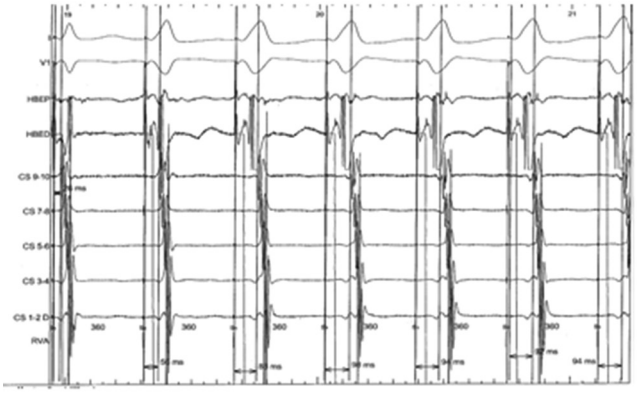


Case 3: AVRT with atrial pre-excitation within transition zone.

Figure 4

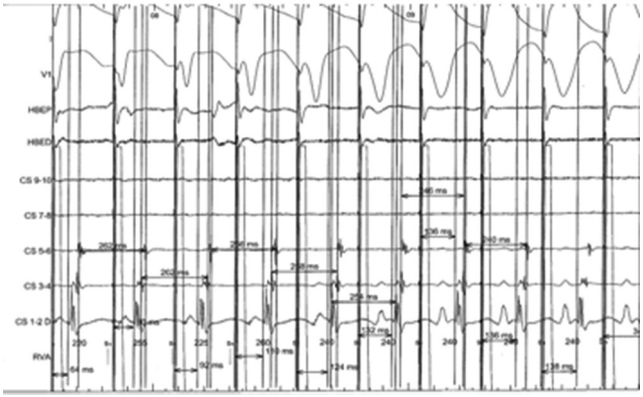
Case 4: AVRT with no atrial perturbation within transition zone.

Figure 5



Case 5: Atrioventricular node re-entry with no fixed stimulus–atrial interval within transition zone.

Figure 6



Case 6: AVRT with fixed stimulus–atrial within transition zone.

Atrial timing perturbation during the transition zone of right ventricular pacing

ORT uses an accessory pathway as the retrograde limb of the re-entrant circuit, and both atrial and ventricular tissue are obligatory components of the tachycardia circuit.

AlMahameed *et al*. [6] showed that during RVP at a cycle length within 40 ms of the TCL, atrial timing is perturbed in 94% of patients with ORT within a TZ.

Zipes *et al*. [7] showed that in the presence of an accessory pathway a single RV extrastimulus administered during SVT at a time when the His bundle is refractory often resulted in pre-excitation of the atrium.

Ross and Uther [5] investigated the effect of His refractory RV extrastimuli during ORT in 99 patients. They found that atrial timing was advanced during SVT in 89% of patients with right-sided AP, 85% of patients with septal AP, and 11% of patients with left-sided APs. In our study, atrial timing was advanced in 100% of patients with septal and right accessory APs and 72% of patients with left-sided APs, and the three cases of AVRT that did not show atrial perturbation were left-sided APs.

Knight *et al*. [2] studied the diagnostic value of different pacing maneuvers during paroxysmal SVT. Perturbation of atrial timing was seen with RV extrastimuli delivered when the His bundle was refractory in 25% of patients with ORT.

Miles *et al*. [8] developed a pre-excitation index to quantify the degree of prematurity required for an RV extrastimulus to result in atrial pre-excitation greater than or equal to 10 ms in patients with ORT. Of 20 patients with left free wall accessory pathways, none had pre-excitation when ventricular extrastimuli were delivered within 45 ms of the TCL, five within 45–75 ms, and the rest greater than or equal to 75 ms.

Our study shows that tachycardia behavior in the TZ of RVP yields similar information to scanned single His refractory ventricular extrastimuli in patients with ORT. We found that atrial timing was perturbed in 86.4% of patients with ORT coincident with fusion QRS complexes. The incidence of perturbation of atrial timing by fusion QRS complexes during RVP was higher in our sample of patients with left free wall APs (72.7%) than previously reported by Knight, Ross, or Miles with single His refractory ventricular extrastimuli.

From our data, we believe that consecutive fusion QRS complexes advance the retrograde limb of the ORT circuit more effectively than a single extrastimulus. AlMahameed *et al*. [6] also reached the same finding and explained that scanned premature ventricular contractions necessarily produce significant long–short sequences that are more likely to produce significant intraventricular conduction delay, which offsets their prematurity. Furthermore, continuous activation from the paced site may 'beat back' the wavefront from the intrinsic tachycardia.

Another interesting finding in this study is that the three patients with no atrial perturbation within the TZ also had a fixed SA interval established within the TZ and the three patients had left-lateral APs. In the three patients, pacing was at 20–40 ms less than TCL, and thus we disagreed with AlMahameed *et al*. [6], who showed that the two patients (of 34 ORT) had minimal atrial pre-excitation of 10 ms within the TZ and explained that when the paced cycle length is only slightly faster than the TCL detection of atrial perturbation may be difficult.

In our study, the TZ of RVP had no effect on atrial timing in 32 (of 36, 88.9%) patients with AVNRT, because paced complexes delivered when the His bundle was refractory did not have access to the AV node.

Only four patients with AVNRT had atrial perturbation, and in two of them this occurred in the first beat with stable morphology. In our study, no bystander APs were present to confound this finding.

Veenhuyzen *et al*. [9] found that when pacing at a cycle length shorter than 40 ms less than TCL, the paced wavefront could penetrate the His bundle and AV node and perturb the atrial cycle length during AT or AVNRT in fewer beats.

We disagreed with AlMahameed *et al*. [6], who found that all AVNRT patients did not show atrial perturbation and this did not occur until at least the second, but most often the third or fourth, paced complex beyond the TZ and explained that the ventricle is not part of the AVNRT re-entrant circuit and the tachycardia circuit would rarely be influenced by the first fully paced QRS complex because the retrograde wavefront has not penetrated sufficiently beyond the His bundle.

Fixed stimulus–atrial interval established in the transition zone of right ventricular pacing

In our study, all (22 patients, 100%) patients with ORT had a fixed SA interval established within the TZ. The fixed SA interval reflects a stable decrease of the atrial cycle length to the paced cycle length. In AVNRT, 32 (out of 36, 88.9%) patients did not show fixed SA interval within TZ. Only four patients had fixed SA interval within TZ, and in three of them this occurred in the first beat with stable morphology.

AlMahameed *et al*. [6] found that none of the patients with AVNRT had a fixed SA interval established within the TZ of RVP. All but one of the 34 patients with ORT had a fixed SA interval established within the TZ. The patient with ORT who failed to meet this criterion had a decrementally conducting right-sided accessory pathway responsible for an increasing SA interval after the TZ but had the diagnosis of ORT confirmed by atrial pre-excitation within the TZ.

Dandamudi *et al*. [10] and Rosman *et al*. [11] found that the positive predictive value of resetting the timing of atrial activation either before or at the time of the first beat showing final paced QRS morphology for AVRT and the positive predictive value of resetting the timing of atrial activation after the first beat showing final paced QRS morphology for AVNRT both exceed 90%.

Note that in our study, in AVNRT, three patients had both atrial perturbation and fixed SA interval within TZ, and two patients had only one of them.

Study limitations

(1) In this study, some cases were retrospective and included only patients with SVT of stable TCL, with either AVNRT or a single AP, in which conventional criteria were adequate for diagnosis and ventricular overdriving pacing (VOP) had been delivered 10–40 ms below the TCL
Apical right VOP greater than 40 ms below the TCL could theoretically reset AVNRT with the last beat in the TZ (first fully paced beat) and VOP less than 10 ms below the TCL might prolong the TZ and only produce minimal atrial advancements, making the estimation of when the SA interval becomes fixed difficult
(2) We did not evaluate how VOP from non-RV apical sites would have influenced the number of beats with fixed SA intervals during the TZ – for example, VOP from the summit of the septum may have resulted in earlier resetting of AVRT, especially in the case of septal AP. In addition, although due care was undertaken to ensure VOP from the RV apex, inadvertent catheter displacement may have led to RV VOP not being fully apical in some cases.

Summary and conclusion

There are different pacing maneuvers for differentiating types of SVT during EPS but no one pacing maneuver can detect the type of SVT accurately. Therefore, combination of more than one pacing maneuvers helps in differentiation.

Many pacing maneuvers depend on RV entrainment during tachycardia – for example PPI – TCL interval, SA – VA interval, and type of response on termination of entrainment.

In our study, we found that during RV pacing at a cycle length within 10–40 ms of the TCL, atrial timing is perturbed in patients with ORT within a TZ that includes QRS complexes showing progressive fusion and the first paced complex with a stable QRS morphology. Perturbation of atrial timing greater than or equal to 15 ms or a fixed SA interval measured from the last beat of the TZ can help in differentiating between AVRT and AVNRT. These criteria do not depend on entrainment success. In addition, the number of QRS complexes with fixed SA interval within TZ can help in localizing the site of AP. Therefore, careful analysis of the beginning of RVP is recommended and may aid in tachycardia diagnosis.

In addition, PPI – TCL interval in AVRT patients helps in localization of the site of AP.

Recommendations

(1) We recommend that analysis of TZ during RV entrainment should be integrated as an important tool in differentiating SVT during EPS
(2) Large prospective studies are further required to establish the role of TZ during RV entrainment in differentiating different types of SVT during EPS.

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Conflicts of interest

There are no conflicts of interest.

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