Electrophysiological Mechanisms and Determinants of Vagal Maneuvers for Termination of Paroxysmal Supraventricular Tachycardia

Zu-Chi Wen, MD; Shih-Ann Chen, MD; Ching-Tai Tai, MD; Chern-En Chiang, MD; Chuen-Wang Chiou, MD; Mau-Song Chang, MD

Background—The vagal maneuvers used for termination of paroxysmal supraventricular reentrant tachycardia (PSVT) appear to involve more complex mechanisms than we have known, and further study should be done to explore the possible mechanisms.

Methods and Results—In this study, 133 patients with PSVT and 30 age- and sex-matched control subjects were included. We assessed the effects of different vagal maneuvers on termination of PSVT and compared baroreflex sensitivity and β-adrenergic sensitivity between the patients with PSVT and control subjects. Out of 85 patients with atrioventricular reciprocating tachycardia (AVRT), vagal maneuvers terminated in 45 (53%). Of these, 28 (33%) terminated in the antegrade limb and 17 (20%) in the retrograde limb. Out of 48 patients with atrioventricular nodal reentrant tachycardia (AVNRT), vagal maneuvers terminated the tachycardia in the antegrade slow pathway (14%) or in the retrograde fast pathway (19%). Baroreflex sensitivity was poorer but isoproterenol sensitivity test better in patients with AVNRT. Poorer antegrade atrioventricular node conduction properties and better vagal response determined successful antegrade termination of AVRT by vagal maneuvers. Poorer retrograde accessory pathway conduction property but better vagal response determined successful retrograde termination of AVRT. Better sympathetic and vagal response associated with poorer retrograde atrioventricular node conduction determined retrograde termination of AVNRT by the Valsalva maneuver.

Conclusions—Both the vagal response and conduction properties of the reentrant circuit determine the tachycardia termination by vagal maneuvers. Improved understanding of the interaction of autonomic and electrophysiological mechanisms in maintaining or terminating PSVT may provide important insight into the pathophysiology of these two tachycardias. (Circulation. 1998;98:2716-2723.)

Key Words: vagus nerve ■ electrophysiology ■ tachycardia ■ Valsalva

Many physical maneuvers that enhance vagal activity have been used for many years to terminate paroxysmal supraventricular tachycardia (PSVT).1–7 Previous studies also showed that atrioventricular nodal reentrant tachycardia (AVNRT) and atrioventricular reciprocating tachycardia (AVRT), which incorporate the atrioventricular (AV) node and accessory pathway (AP) within the circuit, can be interrupted by increasing the refractoriness of the AV node with vagal efferent stimulation; the response rate was related to the level of vagal reaction.6–12 Furthermore, Mehta et al8 found that AVNRT had poorer response to vagal maneuvers than AVRT.

Waxman et al6 had showed that the Valsalva maneuver (VM) is the most powerful physical maneuver for termination of PSVT, and it has a significant vagal effect on AV node conduction. However, Muller et al9 found that some AVRT could be terminated in the retrograde AP conduction by vagal maneuvers, and these patients had longer retrograde AP conduction time. It deserves further study to explore the possible mechanisms.

The purposes of this study were (1) to define the precise electrophysiological mechanism of vagal maneuvers for terminating AVRT and AVNRT; (2) to identify the factors that determine successful termination of tachycardia by the vagal maneuver; and (3) to investigate the autonomic responses in these patients.

Methods

Patient Population

Each patient gave informed consent. Research protocols were approved by the Human Research Committee at Veterans General Hospital-Taipei. All drugs were stopped at least 5 half-lives before
hospital admission. Patients did not have a history of taking amiodarone. Details of the diagnostic electrophysiological study and diagnostic criteria of PSVT have been well described previously. The patients with associated atrial flutter or atrial fibrillation were excluded. Patients who had organic heart disease or other systemic diseases involving the autonomic function (such as diabetic mellitus), those who could not blow into an aneroid manometer to maintain a pressure of 35 mm Hg for 20 seconds, and those with unstable hemodynamics during tachycardia were excluded. Finally, 133 patients (48 male and 85 female patients with mean age of 39±8 years; range 14 to 72) completed all the study protocols. Thirty age- and sex-matched normal volunteers were included as the control group.

Vagal Maneuvers During Sinus Rhythm

After the baseline electrophysiological study, the heart rate and blood pressure (BP) responses to the following physical maneuvers were measured during sinus rhythm. The maneuvers were performed in random order, with a rest period of at least 10 minutes between them. For the carotid sinus massage (CSM), with the patient supine and the head slightly extended, a point on the right or left carotid artery as high up in the neck as possible was firmly massaged against the vertebral column for 5 seconds. Ice to the face (a plastic bag filled with equal parts of ice and water), while the patient was supine, was applied by extending the bag from the patient’s forehead to the tip of the nose for 20 seconds. For the VM, while supine, the patient blew into an aneroid manometer to maintain a pressure of 35 mm Hg for 20 seconds. The patients were instructed not to take deep inspiration before onset of the strain phase. In the case of CSM combined with VM, CSM started 10 seconds after release of the strain phase of the VM. In the case of combining VM, ice to the face, and CSM, the application of ice to the face was started immediately after release of the strain phase of the VM, whereas CSM was performed 10 seconds after release of the strain phase.

Vagal Ratio

Vagal ratio was defined as the ratio of the longest R-R interval during the maneuver to the pretest R-R interval (a mean of 5 beats).

Valsalva-Baroreflex

During phase IV of the VM, the slope of each R-R interval was plotted against the preceding arterial pressure pulse, and a linear regression analysis of these points was performed for the first sustained rise in BP. Valsalva-baroreflex was then estimated as the value of the slope from the regression analysis.

Valsalva Maneuver During PSVT

Tachycardia was induced by programmed electrical stimulation. Once the sustained tachycardia was maintained stable for >5 minutes, the vagal maneuvers were performed in a random order. The protocols of vagal maneuvers were the same as those used in sinus rhythm. Each maneuver was performed 3 times to test its reproducibility in terminating the tachycardia. A vagal maneuver was defined as effective if it terminated tachycardia for at least 2 out of the 3 episodes of induced PSVT.

Baroreflex Sensitivity Study

The baroreflex sensitivity (BRS) study was performed according to the method of Smith et al. In brief, patients received a test bolus injection of phenylephrine (2 μg/kg) to evaluate the magnitude of the resulting increase in systolic BP. In the case of an increase of 15 to 40 mm Hg, phenylephrine injection was repeated at least twice at intervals of >10 minutes. In the case of inadequate BP response (<15 mm Hg increase), the dose was increased by addition of 25 μg per bolus to a maximum of 3.5 μg/kg. Beat-by-beat changes in systolic BP (in mm Hg) and R-R intervals (in milliseconds) were calculated from records. Each R-R interval was plotted against the preceding arterial pressure, and a linear regression analysis of these points was performed for the first sustained rise in BP. The slope was accepted for further analysis only if the correlation coefficient was ≥0.8. At least 3 such slopes were calculated for each patient, and the mean of these was taken as the BRS and expressed in ms/mm Hg.

Isoproterenol Sensitivity Test

β-Adrenergic sensitivity was assessed by calculating the isoproterenol dose response in each patient. Intravenous isoproterenol hydrochloride was given as a rapid 1-mL bolus. The initial dose used was 0.25 μg, and it was thereafter doubled (0.5, 1.0, 2.0, 4.0, and 8.0 μg) until an increase in heart rate up to 25 bpm or a peak heart rate up to 150 bpm was achieved. A 10-minute period was needed between each injection to allow the heart rate to return to baseline value. Isoproterenol chronotropic dose 25 (CD25) was defined as the dose necessary to achieve an increase in heart rate up to 25 bpm.

Treadmill Exercise Test

Each patient underwent treadmill exercise testing according to standard Bruce protocol on the day before the electrophysiological study. The baseline heart rate and maximal heart rate in stage I and stage II of exercise protocol were measured.

Statistical Analysis

All the parametric data were expressed as mean±SD. Parametric data were compared by means of paired and unpaired t tests as appropriate. Comparisons of the nonparametric data were assessed by χ² test with Yates’ correction or Fisher’s exact test. ANOVA was used to analyze the difference among the 3 groups.

Results

Electrophysiological study demonstrated that 85 patients had AVRT mediated by an AP (group 1) and that 48 patients had AVNRT (Table 1).

Group 1: AVRT

Patients with AVRT were classified into 3 subgroups according to the response to VM: Group 1A (n=28, 33%) was defined as patients who had tachycardia termination in the antegrade limb (AV node), group 1B (n=17, 20%) was defined as patients who had termination in the retrograde limb, and group 1C was defined as the other patients without termination of tachycardia (n=40, 47%). Of all maneuvers examined, VM was the most frequently used and consistent in terminating the tachycardias. For patients whose tachycardias were terminated antegradely by VM, tachycardias were interrupted mostly in phase IV (n=25, 29%) and much less in phase I (n=3, 4%). The tachycardia cycle length (TCL) and AH interval showed prolongation before antegrade termination, indicating that vagal tone increased before termination of tachycardia. Tachycardias terminated retrogradely by VM were terminated mostly in phase II (n=16, 19%). The TCL gradually shortened before retrograde termination (Figure 1A), indicating that sympathetic tone increased before termination of tachycardia. Ice to the face (n=5, 6%) and CSM (n=2, 3%) could terminate the tachycardia in the antegrade limb only (Table 2).

Comparisons Between Patients With Antegrade Termination and Patients With Retrograde Termination

The patients with termination of tachycardia in the antegrade limb had significantly longer TCL and poorer antegrade AV node function than those with termination of tachycardia in the retrograde limb (Table 3).
Comparisons Between Patients With and Those Without Termination

The patients without successful termination of tachycardia (group 1C) by vagal maneuver had better antegrade AV node conduction properties and retrograde AP conduction properties and shorter TCL than the patients with termination of tachycardias in the antegrade limb (group 1A). In addition, the group 1C patients had better retrograde AP conduction properties than those with termination of tachycardias in the retrograde limb (group 1B). The BRS and vagal response were significantly better in the subgroups with successful termination (Table 3).

Group 2: AVNRT

Three subgroups were classified according to the responses to VM: Group 2A (n=7, 14%) was defined as patients who had termination of tachycardias in the antegrade limb (slow pathway); group 2B (n=9, 19%) was defined as patients who had termination of tachycardias in the retrograde limb (fast pathway); and group 2C (n=32, 67%) was defined as the patients without termination of tachycardia. Of all maneuvers examined, VM was the most frequently used and consistent in terminating the tachycardias, and CSM was the least (Table 2). Antegrade termination of tachycardia by VM occurred mostly in phase IV (n=6, 13%) and much less in phase I (n=1, 2%). The TCL all showed prolongation before antegrade termination (Figure 1B). Tachycardia terminated retrogradely by VM were mostly in phase II (n=9, 19%) (Table 2).

Comparisons Between Patients With Antegrade Termination and Patients With Retrograde Termination

The patients with termination in the retrograde limb had poorer retrograde AV node conduction properties but better antegrade AV node conduction properties and shorter TCL than those patients with termination in the antegrade limb (Table 4). The BRS and vagal response were similar between these 2 subgroups.

Comparisons Between Patients With and Those Without Termination

The antegrade slow AV node conduction properties were significantly better than their own retrograde fast AV node in patients with retrograde termination; such a phenomenon was not found in the other 2 subgroups (Table 4). The patients with termination had better BRS and vagal response than those without termination (Table 4).

Comparisons Among Group 1, Group 2, and Control Group

Vagal maneuvers were more effective in terminating AVRT than AVNRT (53% vs 33%, P<0.05) (Table 2). Patients with AVNRT had lower BRS and vagal response than those with AVRT or the normal control group (Table 1 and Figure 2A). However, PR interval did not change in any group (Figure 2B). VM also induced more prolongation of the R-R interval during sinus rhythm in patients with AVRT than AVNRT (Figure 2A). The maximal heart rate in 24-hour Holter recordings was lower in patients with AVNRT, even though their mean heart rate was similar to the other 2 groups. The heart rate before exercise testing was also lower in these patients; however, they had better response to isoproterenol and more significant increase of heart rate in stage I of treadmill exercise testing, indicating that the patients with AVNRT might have better sympathetic efferent activity (Table 5).

Comparisons Among Different Vagal Maneuvers

Phenylephrine infusion induced better baroreflex than VM (6.3±2.4 vs 3.5±1.8 ms/mm Hg in group 1 and 4.5±3.1 vs 2.2±1.3 ms/mm Hg in group 2, both P<0.001). VM was the most effective vagal maneuver in termination of the tachycardia when compared with ice to the face (63/133 vs 7/133, P<0.00001) or CSM (63/133 vs 2/133, P<0.00001) (Table 2). VM also induced the most significant prolongation of the R-R interval during sinus rhythm or during PSVT (Figure 3).
Figure 1. A, Shortening of R-R (380 to 310 ms) and AH (160 to 110 ms) interval before retrograde termination of AVRT during phase II of VM. BP gradually decreases during this phase. B, Prolonging of AH interval (310 to 340 ms) before antegrade termination of AVNRT. BP and AH are gradually increased during phase IV of VM.
TABLE 2. Different Vagal Maneuvers in Terminating PSVT

<table>
<thead>
<tr>
<th></th>
<th>AVRT (n=85)</th>
<th>AVNRT (n=48)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Successful termination</td>
<td>45 (53%)</td>
<td>16 (33%)</td>
<td>0.032</td>
</tr>
<tr>
<td>Phase of termination during VM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>3 (4%, A)</td>
<td>1 (2%, A)</td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>16 (19%, R)</td>
<td>9 (19%, R)</td>
<td></td>
</tr>
<tr>
<td>III</td>
<td>1 (1%, R)</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>IV</td>
<td>25 (28%, A)</td>
<td>6 (13%, A)</td>
<td>0.5</td>
</tr>
<tr>
<td>Ice to face</td>
<td>5 (6%, A)</td>
<td>2 (4%, A)</td>
<td>0.98</td>
</tr>
<tr>
<td>CSM</td>
<td>2 (2%, A)</td>
<td>0</td>
<td>0.74</td>
</tr>
<tr>
<td>VM+cold face</td>
<td>45 (53%)</td>
<td>16 (33%)</td>
<td>0.032</td>
</tr>
<tr>
<td>VM+CSM</td>
<td>45 (52%)</td>
<td>16 (33%)</td>
<td>0.032</td>
</tr>
<tr>
<td>Ice to face+CSM</td>
<td>5 (5%)</td>
<td>1 (2%)</td>
<td>0.56</td>
</tr>
<tr>
<td>VM+cold face+CSM</td>
<td>45 (53%)</td>
<td>16 (33%)</td>
<td>0.032</td>
</tr>
</tbody>
</table>

A indicates antegrade block; R, retrograde block.

Discussion

Main Findings
The main findings of this study were as follows:

1. Vagal activity was more blunt in patients with AVNRT.
2. Vagal maneuvers were more effective in terminating AVRT than in terminating AVNRT.
3. Poorer antegrade AV node conduction properties and better vagal responses determined successful antegrade termination of AVRT by vagal maneuvers.
4. Poorer retrograde AP conduction properties with better vagal responses determined successful retrograde termination of AVRT.
5. Better sympathetic and vagal response associated with poorer retrograde AV node conduction properties determined retrograde termination of AVNRT by VM.
6. VM could terminate PSVT in phase I, II, III, or IV, and its effects depended on the patient’s autonomic responses and conduction properties of the reentrant circuit.

Autonomic Dysfunction in Patients With AVNRT
This study demonstrated that the patients with AVNRT had poorer BRS than normal volunteers. In addition, the sympathetic efferent activity evaluated by the isoproterenol sensitivity test and treadmill exercise test was more active in patients with AVNRT compared with normal volunteers. Both the sympathetic tone and vagal tone change with age, and they are also different between female and male subjects.16–19 However, the age and sex distribution were similar among the 3 patient groups, and we also excluded patients with any systemic disease or any autonomic neuropathy.

Mehta et al8 found that AVRT was more easily terminated than AVNRT by VM, but they only suspected that this effect might be due to differences in antegrade AV node function between AVRT and AVNRT. Our study demonstrated that the vagal activity was impaired in patients with AVNRT, but the true mechanism is unknown.

The canine model has demonstrated that the effects of baroreflex on sinoatrial (SA) node and AV node had a

TABLE 3. Clinical and Electrophysiological Characteristics and Responses to Different Vagal Maneuvers in Patients With AVRT

<table>
<thead>
<tr>
<th>No.</th>
<th>Failure (Group C)</th>
<th>Total</th>
<th>Ant-Ter (Group 1A)</th>
<th>Ret-Ter (Group 1B)</th>
<th>Group 1C vs 1A</th>
<th>Group 1C vs 1B</th>
<th>Group 1A vs 1B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>38 ± 11</td>
<td>40</td>
<td>28</td>
<td>17</td>
<td>0.54</td>
<td>0.84</td>
<td>0.71</td>
</tr>
<tr>
<td>Sex, F/M</td>
<td>47/38</td>
<td>25/15</td>
<td>12/16</td>
<td>10/7</td>
<td>0.001</td>
<td>0.47</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>TCL, ms</td>
<td>341 ± 45</td>
<td>326 ± 38</td>
<td>381 ± 46</td>
<td>334 ± 27</td>
<td>&lt;0.001</td>
<td>0.73</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Electrophysiological characteristics</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ant-AVN 1:1, ms</td>
<td>324 ± 50</td>
<td>310 ± 53</td>
<td>361 ± 34</td>
<td>310 ± 14</td>
<td>&lt;0.05</td>
<td>0.73</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Ant-AVNERP, ms</td>
<td>266 ± 41</td>
<td>253 ± 39</td>
<td>286 ± 41</td>
<td>274 ± 21</td>
<td>&lt;0.05</td>
<td>0.21</td>
<td>0.58</td>
</tr>
<tr>
<td>Retro-AP 1:1, ms</td>
<td>279 ± 52</td>
<td>258 ± 37</td>
<td>303 ± 46</td>
<td>298 ± 35</td>
<td>&lt;0.05</td>
<td>&lt;0.05</td>
<td>0.87</td>
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<tr>
<td>Retro-APERP, ms</td>
<td>266 ± 39</td>
<td>252 ± 23</td>
<td>290 ± 43</td>
<td>297 ± 27</td>
<td>&lt;0.05</td>
<td>&lt;0.05</td>
<td>0.28</td>
</tr>
<tr>
<td>Δ1:1(Ant-AVN/Retro-AP), ms</td>
<td>3 ± 47</td>
<td>36 ± 42</td>
<td>54 ± 38</td>
<td>9 ± 37</td>
<td>0.56</td>
<td>&lt;0.05</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>ΔERP(Ant-AVN/Retro-AP), ms</td>
<td>−2 ± 39</td>
<td>0 ± 39</td>
<td>−2 ± 44</td>
<td>−20 ± 25</td>
<td>0.61</td>
<td>&lt;0.05</td>
<td>&lt;0.05</td>
</tr>
</tbody>
</table>

Vagal ratio obtained during tachycardia

By valsalva: 1.2 ± 0.1; 1.1 ± 0.1; 1.3 ± 0.1; 1.4 ± 0.2
By cold face: 1.1 ± 0.0; 1.0 ± 0.0; 1.1 ± 0.1; 1.1 ± 0.1
By right CSM: 1.0 ± 0.0; 1.0 ± 0.0; 1.1 ± 0.0; 1.1 ± 0.0
By left CSM: 1.0 ± 0.0; 1.0 ± 0.0; 1.1 ± 0.0; 1.1 ± 0.0
Valsalva-baroreflex,* ms/mm Hg: 3.5 ± 1.8; 2.1 ± 1.2; 4.8 ± 2.2; 4.6 ± 2.4
BRS, ms/mm Hg: 6.3 ± 2.4; 5.8 ± 2.2; 6.8 ± 2.3; 6.5 ± 3.0

Ant-Ter indicates termination in antegrade direction; Ret-Ter, termination in retrograde direction; Ant-AVN 1:1, antegrade AV node 1-to-1 conduction; Ant-AVNERP, antegrade AV node effective refractory period; Retro-AP 1:1, retrograde AP 1-to-1 conduction; Retro-APERP, retrograde AP effective refractory period; Δ1:1(Ant-AVN/Retro-AP), difference of 1-to-1 conduction property of antegrade AV node and retrograde AP; ΔERP(Ant-AVN/Retro-AP), difference of effective refractory period of antegrade AV node and retrograde AP.

*Baroreflex obtained by VM.
Mechanism of Vagal Maneuvers in Terminating AVNRT

There was no previous report about VM-mediated retrograde termination of AVNRTs. This study demonstrated that 19% of AVNRT could be terminated by VM in the retrograde limb. These patients had poorer retrograde AV node conduction properties than those without termination of the tachycardia in the retrograde limb. Besides, these patients also had better BRS. In phase II of the VM, the activation of sympathetic tone and withdrawal of vagal tone increase the AV node conduction velocity and the impulse conducting from antegrade slow AV node reaches the retrograde AV node much earlier; if the retrograde AV node is still refractory, the impulse cannot conduct and the tachycardia will be terminated. Such a possibility increases when the retrograde conduction property is poorer.

Patients with VM-mediated antegrade termination of AVNRT were associated with significantly better BRS than those without termination, even though both subgroups had similar AV node conduction properties. On the other hand, retrograde AV node conduction properties in these patients were significantly better than those with retrograde termination. Therefore these tachycardias could not be terminated by the VM in phase II or III as those of retrograde termination, even though both subgroups had similar Valsalva-baroreflex activity.

Mechanism of Vagal Maneuvers in Terminating AVRT

The conditions required to maintain a stable orthodromic AVRT include sufficient delay of antegrade AV node conduction time and adequately fast conduction velocity of retrograde AP. The retrograde conduction properties were poorer in patients with VM-mediated retrograde termination of AVRT than those in patients without termination of tachycardia. The poorer retrograde AP conduction properties provided more chances for the impulse conducting from the antegrade AV node to meet the refractory period of the AP. The activation of sympathetic activity with withdrawal of the vagal response during phases II and III of the VM enhances the antegrade AV node conduction velocity. The more antegrade AV node conduction is enhanced, the easier antegrade-conducted impulses meet the refractory period of the AP.

The patients with VM-mediated antegrade termination of AVRTs had poorer antegrade AV node conduction properties than those without termination. Furthermore, these patients had better Valsalva-baroreflex. Because the antegrade AV node conduction was poorer and the Valsalva-baroreflex was positive correlation. The effects of vagal activity on the SA node can roughly represent its effect on the AV node. Patients with AVNRT had lower Valsalva-baroreflex activity but better sympathetic efferent activity. This could explain why the success rate of VM-mediated termination of tachycardia was lower in these patients.

TABLE 4. Characteristics of Termination of AVNRT by Different Vagal Maneuvers

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Total</th>
<th>Failure (Group 2C)</th>
<th>Success</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Ant-Ter (Group 2A)</td>
<td>Ret-Ter (Group 2B)</td>
</tr>
<tr>
<td>No.</td>
<td>48</td>
<td>32</td>
<td>7</td>
<td>9</td>
</tr>
<tr>
<td>Age, y</td>
<td>41±13</td>
<td>42±12</td>
<td>41±13</td>
<td>39±16</td>
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<td>Sex, F/M</td>
<td>38/10</td>
<td>25/7</td>
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<td>7/2</td>
</tr>
<tr>
<td>Electrophysiological characteristics</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>TCL, ms</td>
<td>364±41</td>
<td>371±49</td>
<td>368±40</td>
<td>337±48</td>
</tr>
<tr>
<td>Ant-SAVN 1:1, ms</td>
<td>346±51</td>
<td>353±45</td>
<td>343±59</td>
<td>326±35</td>
</tr>
<tr>
<td>Ant-SAVNERP, ms</td>
<td>271±34</td>
<td>277±37</td>
<td>257±21</td>
<td>262±33</td>
</tr>
<tr>
<td>Retro-FAVN 1:1, ms</td>
<td>341±62</td>
<td>339±50</td>
<td>323±30</td>
<td>364±54</td>
</tr>
<tr>
<td>Retro-FAVNERP, ms</td>
<td>278±60</td>
<td>274±43</td>
<td>263±23</td>
<td>303±50</td>
</tr>
<tr>
<td>ΔAVN1:1(Ant-S/Retro-F), ms</td>
<td>3±47</td>
<td>11±45</td>
<td>20±39</td>
<td>−40±57</td>
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<td>ΔAVNERP(Ant-S/Retro-F), ms</td>
<td>−8±38</td>
<td>1±36</td>
<td>−6±24</td>
<td>−39±54</td>
</tr>
<tr>
<td>Valsalva ratio obtained during tachycardia</td>
<td></td>
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</tr>
<tr>
<td>By Valsalva</td>
<td>1.1±0.1</td>
<td>1.1±0.1</td>
<td>1.2±0.1</td>
<td>1.3±0.2</td>
</tr>
<tr>
<td>By cold face</td>
<td>1.0±0.1</td>
<td>1.0±0.0</td>
<td>1.1±0.1</td>
<td>1.1±0.1</td>
</tr>
<tr>
<td>By right CSM</td>
<td>1.0±0.0</td>
<td>1.0±0.0</td>
<td>1.1±0.0</td>
<td>1.1±0.0</td>
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<tr>
<td>By left CSM</td>
<td>1.0±0.0</td>
<td>1.0±0.0</td>
<td>1.1±0.0</td>
<td>1.1±0.0</td>
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<tr>
<td>Valsalva-baroreflex,* ms/mm Hg</td>
<td>2.2±1.1</td>
<td>2.0±1.2</td>
<td>2.8±1.2</td>
<td>2.6±1.4</td>
</tr>
<tr>
<td>BRS, ms/mm Hg</td>
<td>4.5±3.1</td>
<td>3.0±2.5</td>
<td>7.3±2.3</td>
<td>7.8±3.0</td>
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</tbody>
</table>

Ant-Ter indicates termination in antegrade direction; Ant-SAVN 1:1, antegrade slow AV node 1-to-1 conduction; Ant-SAVNERP, antegrade slow AV node effective refractory period; Retro-FAVN 1:1, retrograde fast AV node 1-to-1 conduction; Retro-FAVNERP, retrograde fast AV node effective refractory period; and Ret-Ter, termination in retrograde direction.

*Baroreflex obtained by VM.
better in these patients, tachycardia was more easily terminated by increase of vagal tone.

Mehta et al. found only 1 patient with VM-mediated retrograde termination of AVRTs in a total of 24 patients. They suggested that Valsalva-baroreflex may have a significant effect on the APs or their atrial insertions. Furthermore, Muller et al. showed that AVRTs in pediatric patients with poorer retrograde conduction properties of APs were often retrogradely terminated by vagal maneuvers and adenosine.

However, the phase with retrograde termination of the AVRT during the VM was not mentioned. We have demonstrated that retrograde termination during phase II or III of the VM was due to vagal withdrawal and sympathetic activation–induced enhanced antegrade AV node conduction. Further-

**Figure 2.** Different effects of vagal maneuvers on PR interval in sinus rhythm. $\Delta PR(\%)$ and $\Delta RR(\%)$ indicate percentage change of PR and R-R intervals. CSM indicates carotid sinus massage; IF, ice to the face; and VM, Valsalva maneuver. *P<0.05.

**Figure 3.** Different combinations of vagal maneuvers on R-R interval in sinus rhythm (A) or tachycardia (B). $\Delta RR(\%)$ indicates percentage change of R-R interval. VM induced most significant prolongation of R-R intervals during sinus rhythm and PSVT. IF indicates ice to the face; CSM, carotid sinus massage.

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**TABLE 5. Heart Rate Response During Different Autonomic Tests**

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>AVRT</th>
<th>AVNRT</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>24-Hour heart rate in Holter monitoring, bpm</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>70±10</td>
<td>71±10</td>
<td>68±9</td>
</tr>
<tr>
<td>Maximal</td>
<td>139±21</td>
<td>142±20</td>
<td>130±17</td>
</tr>
<tr>
<td>Minimal</td>
<td>48±5</td>
<td>50±6</td>
<td>47±5</td>
</tr>
<tr>
<td><strong>Heart rate in treadmill exercise test, bpm</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pretest</td>
<td>95±6</td>
<td>98±5*</td>
<td>90±6†</td>
</tr>
<tr>
<td>Stage I</td>
<td>128±8</td>
<td>124±8*</td>
<td>136±10†</td>
</tr>
<tr>
<td>Stage II</td>
<td>147±10</td>
<td>146±12</td>
<td>149±11</td>
</tr>
<tr>
<td>Isoproterenol (CD$_{25}$), µg</td>
<td>1.65±0.42</td>
<td>1.94±0.63*</td>
<td>1.12±0.37†</td>
</tr>
</tbody>
</table>

P<0.05, *compared with control group; †compared with AVRT group.
more, Waxman et al. demonstrated that isoproterenol can terminate AVRT in its retrograde AP conduction by sufficiently increasing antegrade AV node conduction. Only if the tachycardia was retrogradely terminated by the VM during phase I or IV, we can reasonably say that such effect was most likely due to enhancement of baroreflex.

**Effects of Different Vagal Maneuvers**

Our data showed that the VM was the most effective physical maneuver in terminating tachycardias. Greater vagal potency of the VM over CSM has previously been reported by Waxman et al. and Mehta et al. CSM was usually ineffective in this study. This is in keeping with our clinical experience, but not with some of previous studies. The reason for this discrepancy is not clear, but it could be related to the fact that most of our patients were referred for catheter ablation and their PSVTs were more refractory to medical control than those in other studies.

**Role of Sympathetic Tone**

The VM decreases preload and BP during strain phase, which activates endogenous sympathetic tone. The activated catecholamine will stimulate α-adrenergic receptors to elevate BP and stimulate β-adrenergic receptors to increase heart rate. Thus the R-R interval is shortened in phases II and III and finally prolonged in phase IV. Prolongation of the R-R interval depended on the net effect of vagal reflex and chronotropic effect mediated by β-adrenergic receptor activation. On the other hand, phenylephrine injection mainly activated α-adrenergic receptors and R-R interval gradually prolonged without activation of β-adrenergic receptor-mediated chronotropic effect. Waxman et al. have shown that an adequate dose of phenylephrine infusion can terminate the PSVT that cannot be terminated by the VM. Interaction of vagal and sympathetic activities also could modulate AV node conduction. Thus overactivation of sympathetic activity with positive dromotropic effect might be one of the reasons for failed antegrade termination of PSVT by the VM. In the AVRT group, the patients without termination of tachycardia by vagal maneuvers had similar BRS as those with termination, but their VM-induced baroreflex was much poorer. It was most likely due to their stronger β-adrenergic activity. Similarly, this study also demonstrated that the patients with AVNRT were more sensitive to β-adrenergic stimulation than those with AVRT. This finding can explain the mechanism of poorer vagal response as well as lower tachycardia termination rate.

**Study Limitations**

(1) Vagal activity should have effects on both antegrade and retrograde AV node conduction. However, this study did not provide such data. It is very difficult to evaluate the effect of baroreflex on the antegrade slow AV node conduction.

(2) The possibility of parallel effects of autonomic functions on the AV node and SA node deserve further study.

**Conclusions**

Both autonomic response and conduction properties of the tachycardia circuit determined its termination by vagal maneuvers. Better BRS but poorer conduction properties determined termination of tachycardia in the antegrade or retrograde limb. Improved understanding of the interaction of autonomic and electrophysiological mechanisms in maintaining or terminating PSVT may provide important insight into treatment strategies as well as the pathophysiology of these two tachycardias.

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**References**


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Zu-Chi Wen, Shih-Ann Chen, Ching-Tai Tai, Chern-En Chiang, Chuen-Wang Chiou and Mau-Song Chang

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