Determination of Inadvertent Atrial Capture During Para-Hisian Pacing

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Background—Inadvertent capture of the atrium will lead to spurious results during para-Hisian pacing. We sought to establish whether the stimulation-to-atrial electrogram interval at the proximal coronary sinus (stim-PCS) or high right atrium (stim-HRA) could signal inadvertent atrial capture.

Methods and Results—Para-Hisian pacing with and without intentional atrial capture was performed in 31 patients. Stim-HRA and stim-PCS intervals were measured with atrial capture, His plus para-Hisian ventricular (H+V) capture, and para-Hisian ventricular (V) capture alone. The mean stim-HRA interval was significantly shorter with atrial capture (66±18 ms) than with H+V (121±27 ms, P<0.001) or V capture alone (174±38 ms, P<0.001). The mean stim-PCS interval was significantly shorter with atrial capture (51±16 ms) than with H+V (92±22 ms, P<0.001) or V capture alone (146±33 ms, P<0.001). A stim-PCS <60 ms (stim-HRA <70 ms) was observed only with atrial capture. A stim-PCS >90 ms (stim-HRA >100 ms) was observed only in the absence of atrial capture. A stim-HRA of <85 ms was highly specific and stim-PCS of <85 ms highly sensitive at identifying atrial capture. Stim-HRA intervals of 75 to 97 ms and stim-PCS intervals of 65 to 88 ms were observed with either atrial, His, or para-Hisian ventricular capture without atrial capture. In this overlap zone, all patients demonstrated a stim-PCS or stim-HRA interval prolongation of at least 20 ms when the catheter was advanced to avoid deliberate atrial pacing. The QRS morphology was of limited value in distinguishing atrial capture due to concurrent ventricular or H+V capture, as observed in 20 of 31 (65%) patients.

Conclusions—Stim-PCS and stim-HRA intervals can be used to monitor for inadvertent atrial capture during para-Hisian pacing. A stim-PCS <60 ms (or stim-HRA <70 ms) and stim-PCS >90 ms (or stim-HRA >100 ms) were observed only with and without atrial capture, respectively, but there was significant overlap between these values. Deliberate atrial capture and loss of capture reliably identifies atrial capture regardless of intervals. (Circ Arrhythm Electrophysiol. 2011;4:510-514.)

Key Words: electrophysiology  tachyarrhythmias  bundle of His  pacing

Para-Hisian pacing is a commonly used electrophysiological maneuver to help distinguish retrograde septal accessory pathway (AP) conduction versus that over the normal AV conduction system. During this maneuver, the correct diagnosis depends on pacing and capturing the para-Hisian region—either the His and para-Hisian ventricular myocardium (H+V) or the para-Hisian ventricular myocardium (V) alone (pure His capture infrequently is observed). Inadvertent capture of the atrium during this maneuver may lead to spurious results (Figures 1 and 2). This is not always evident because the pacing electrodes are saturated during pacing, and the proximal pair may not be adequate to define the stimulus-to-atrial (stim-atrial) interval at this site. Identification of inadvertent atrial capture with concurrent V or H+V capture is clearly critical to avoid misinterpretation of this maneuver. The purpose of this study was to determine whether conduction times from the stim-atrial recording sites in either standard high right atrial (HRA) position or near the orifice of the coronary sinus (CS) were sufficiently short to identify direct inadvertent atrial capture as opposed to conduction to the atria through the anomalous or normal AV conduction systems during the para-Hisian pacing maneuver.

Clinical Perspective on p 514

Methods

We prospectively analyzed intracardiac recordings in patients undergoing an electrophysiology study who had the placement of a CS catheter, a His catheter (or catheter capable of His pacing), and an HRA catheter. Thirty-one patients undergoing electrophysiology study for documented or suspected supraventricular tachycardia were included in this study. None had anterograde preexcitation. Patients with prior ablation, with an implanted cardiac device, or with

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structural heart disease were excluded. All patients had medications administered for supraventricular tachycardia stopped at least 5 half lives before the procedure. All patients provided written informed consent.

At electrophysiology study, catheters were introduced percutaneously and placed at the high lateral right atrium, at the His bundle region, and in the CS with the proximal CS (PCS) bipoles at the CS ostium. Surface ECGs and bipolar endocardial electrograms were stored on a computer-based digital amplifier/recorder system (CardioLab; Prucka GE; Houston, TX). Intracardiac electrograms were filtered from 30 to 500 Hz and measured using online calipers at a sweep speed of 100 mm/s.

Para-Hisian pacing was undertaken from the proximal and distal bipoles of the His catheter where a His bundle potential was recorded with an equal atrial and ventricular electrogram. Stimulation was delivered using a pulse of 20-V output and 2-ms pulse width at rates faster than the sinus rate. At this output, the pacing spike typically captured the atrium and H+V. The His catheter was withdrawn slightly to the atrium to confirm atrial capture and then advanced toward the ventricle to ensure loss of atrial capture while maintaining H+V capture. Finally, pacing output was gradually reduced to lose His capture and obtain V capture alone.

The stim-atrial electrogram interval at the PCS (stim-PCS) and HRA (stim-HRA) were measured with atrial capture, H+V capture, and V capture alone. Stim-PCS and stim-HRA were measured from the stimulus artifact to the earliest rapid deflection at the PCS and HRA catheters, respectively. Two or more beats were confirmed and checked for reproducibility with stim-HRA and stim-PCS intervals. Deliberate pure atrial capture was demonstrated in all patients. The stim-atrial intervals associated with pure atrial capture (with QRS morphology similar to sinus rhythm [SR]) were used to categorize the stim-atrial intervals observed with atrial plus concurrent V or H+V capture. The stim-PCS and stim-HRA intervals were compared with atrial capture, H+V capture, and V capture alone. Receiver operating characteristic curves were constructed to determine stim-PCS and stim-HRA cutoffs to distinguish between atrial capture and V capture alone.

**Statistical Analysis**

Continuous variables are expressed as mean ± SD. Continuous variables were compared by use of a 2-tailed Student t test. Atrial capture was compared to H+V capture and to V capture alone. Receiver operating characteristic curves were constructed to determine stim-PCS and stim-HRA cutoffs to distinguish between atrial capture and V capture alone.

**Figure 1.** Para-Hisian pacing sequence. The stimulus-to-atrial interval at the high right atrium and at the proximal coronary sinus remains constant with current reduction, resulting in a widening of the QRS. This might be mistaken to indicate the presence of a septal accessory pathway, except that stimulus-to-atrial interval at the proximal coronary is <60 ms, indicating direct atrial capture (see text). Slight repositioning to lose atrial capture reveals His capture with prolongation of the stimulus-to-atrial interval and further prolongation when His capture is lost, confirming absence of a septal accessory pathway. Stimulus-to-atrial intervals in milliseconds are shown at their respective leads.

**Figure 2.** Para-Hisian pacing sequence. Current is reduced from the atrial capture to the ventricular capture, with widening of the QRS suggesting loss of His capture and no septal accessory pathway. However, the stimulus-to-atrial interval at the proximal coronary sinus is only 55 ms, confirming atrial capture. Slight repositioning more distally again narrowed the QRS, suggesting His capture, but the stimulus-to-atrial interval at the proximal coronary sinus is now 111 ms, confirming the presence of a septal accessory pathway without atrial capture. Finally, during para-Hisian pacing, a wide beat with concurrent atrial and ventricular capture was observed, which also could lead to spurious interpretation if not recognized as atrial capture. Stimulus-to-atrial intervals in milliseconds are shown at their respective leads.
atrial noncapture. \( P < 0.025 \) was considered significant to correct for multiple comparisons. The authors had full access to the data and take full responsibility for their integrity. All authors have read and agreed to the manuscript as written.

**Results**

Thirty-one patients (13 men and 18 women) aged 48±19 years (median, 46 years; range, 15 to 87 years) were included. Four had a septal AP, and 27 had none. Para-Hisian pacing was successfully performed in all patients, with atrial capture obtained in all. All patients demonstrated VA conduction.

The mean stim-HRA interval was significantly shorter with atrial capture (mean, 66±18 ms; range, 37 to 97 ms) than with \( H + V \) capture (mean, 121±27 ms; range, 75 to 170 ms; \( P < 0.001 \)) or V capture alone (mean, 174±38 ms; range, 112 to 250 ms; \( P < 0.001 \)). The mean stim-PCS interval was significantly shorter with atrial capture (mean, 51±16 ms; range, 29 to 88 ms) than with \( H + V \) capture (mean, 92±22 ms; range, 65 to 140 ms; \( P < 0.001 \)) or V capture alone (mean, 146±33 ms; range, 83 to 228 ms; \( P < 0.001 \)) (Figure 3).

A stim-PCS <60 ms was observed only with atrial capture, and a stim-PCS >90 ms was observed only in the absence of atrial capture. Similarly, a stim-HRA <70 ms was observed only with atrial capture, and stim-HRA >100 ms was observed only in the absence of atrial capture. The area under the receiver operating characteristic curve for identifying atrial capture by stim-PCS was 0.9435 (95% CI, 0.8872 to 0.9999; \( P < 0.001 \)) and by stim-HRA, 0.9662 (95% CI, 0.9276 to 0.9999; \( P < 0.001 \)) (Figure 4, Table). A stim-HRA interval <85 ms had a sensitivity of 82% (95% CI, 63% to 94%) and specificity of 96% (95% CI, 82% to 99.9%) at identifying atrial capture. A stim-PCS interval of <85 ms had a sensitivity of 97% (95% CI, 82% to 99.9%) and specificity of 52% (95% CI, 33% to 71%) at identifying atrial capture. Thus, an overlap zone existed (ie, stim-HRA interval between 75 and 97 ms and stim-PCS interval between 65 and 88 ms) where atrial capture could not be determined for certain merely by measuring stim-atrial intervals (Figure 3). A mean stim-HRA interval prolongation of 50±18 ms (range, 23 to 80 ms) and stim-PCS interval prolongation of 41±17 ms (range, 21 to 82 ms) was observed when the His catheter was advanced marginally to eliminate atrial capture and obtain only \( H + V \) capture. Thus, all patients demonstrated a stim-atrial interval prolongation of at least 20 ms when the catheter was advanced to eliminate atrial capture and obtain only \( H + V \) capture.

**Figure 3.** Scatterplot demonstrating stimulus-to-atrial intervals during A capture, \( H + V \) capture, and V capture alone. A indicates atrial; \( H + V \), His plus para-Hisian ventricular; stim-HRA, stimulus-to-atrial electrogram interval at the high right atrium; stim-PCS, stimulus-to-atrial electrogram interval at the proximal coronary sinus; V, ventricular.

**Figure 4.** ROC curves for stim-PCS and stim-HRA to identify atrial capture. ROC indicates receiver operating characteristic. Other abbreviations as in Figure 3.
capture during the para-Hisian maneuver (Figure 1). Alternatively, all patients demonstrated a stim-atrial interval shortening of at least 20 ms when the catheter was pulled back to regain atrial capture (Figure 5).

The QRS morphology and width were not useful to confirm or exclude atrial capture because of concurrent capture of V or H/V. The minimal QRS width change from atrial capture (ie, pure atrial or atrial and H/V or atrial V alone) to atrial noncapture (ie, V or H/V capture) ranged from 0 to 83 ms (median, 22 ms; mean, 23 ± 18 ms). Furthermore, in 20 of 31 (65%) patients, the QRS width associated with atrial capture was within 10 ms to that associated with V capture alone (Figures 1 and 2) or H/V capture.

**Discussion**

The major findings of the current study are the following: (1) A stim-PCS interval < 60 ms (or stim-HRA < 70 ms) is observed only with direct atrial capture; (2) a stim-PCS interval > 90 ms (or stim-HRA > 100 ms) is observed only in the absence of atrial capture; (3) a shortening of stim-atrial at the CS orifice or at the HRA by 20 ms using a small catheter adjustment to create deliberate atrial capture reliably ensures that inadvertent atrial capture had not occurred; (4) in any single patient, direct atrial capture provided the shortest stim-atrial interval; and (5) in any single patient, V capture alone resulted in the longest stim-atrial interval with the widest QRS. To our knowledge, this study is the first to present a method that may assist in identifying inadvertent atrial capture during the para-Hisian maneuver.

The para-Hisian pacing maneuver is very useful in clinical electrophysiology, but care must be taken to avoid technical and interpretative pitfalls. Inadvertent atrial capture during the maneuver may give the erroneous impression of retrograde conduction over a septal AP in the absence of an AP (Figure 1) or retrograde conduction over the AV node in the presence of an AP (Figure 2). Intuitively, direct atrial capture should give a very-short stim-atrial interval. This may be difficult to recognize because the most useful electrogram to assess atrial capture is that in the pacing channel (ie, the distal bipolar His pair) and is saturated at least to some degree during pacing. The proximal pair of the pacing catheter may not be a good surrogate because of poor contact and is itself distant from the site of interest. In addition, the pacing catheter may capture the ventricular muscle and His bundle, which would further make the atrial electrogram at the pacing site difficult to interpret.

We initiated the present study with the hypothesis that the stim-atrial interval measured at the CS orifice or HRA should be shortest with direct atrial capture compared with retrograde conduction through an AP or the His bundle, and an absolute value may exist to characterize atrial capture. Indeed, direct atrial capture was characterized by very-short intervals. Stim-PCS intervals < 60 ms or stimulus-HRA intervals < 70 ms were observed only with direct atrial capture (specificity 100%), whereas intervals > 90 ms at the PCS or 100 ms at the HRA were observed only in the absence of direct capture (specificity 100%). Outside these limits, it was not possible to reliably distinguish direct atrial capture

![Table. Stim-HRA and Stim-PCS Test Performance To Identify Atrial Capture](http://circep.ahajournals.org/article-figures/123.png)

<table>
<thead>
<tr>
<th>Test</th>
<th>Cutoff, ms</th>
<th>Sensitivity, %</th>
<th>Specificity, %</th>
</tr>
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<tbody>
<tr>
<td>Stim-PCS</td>
<td>64</td>
<td>79</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>72</td>
<td>90</td>
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<tr>
<td></td>
<td>91</td>
<td>100</td>
<td>41</td>
</tr>
<tr>
<td>Stim-HRA</td>
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<td>64</td>
<td>100</td>
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<tr>
<td></td>
<td>81</td>
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Stim-HRA indicates stimulus-to-atrial electrogram interval at the high right atrium; stim-PCS, stimulus-to-atrial electrogram interval at the proximal coronary sinus.

![Figure 5. Para-Hisian pacing example](http://circep.ahajournals.org/article-figures/123.png)

The catheter is initially in the region of interest, and the QRS duration and morphology of the first paced cycle suggest V capture alone. Nonetheless, the stimulus-to-atrial intervals are relatively short, and A capture cannot be ruled out. With slight increase in current, the QRS narrows, suggesting H/V capture, but the stimulus-to-atrial interval remains short. Slight catheter pullback (third cycle) results in shortening of the stimulus-to-atrial interval, confirming A capture in addition to H/V capture. Thus, the first cycles demonstrate the presence of a septal accessory pathway while ruling out inadvertent A capture. The QRS widths are provided under their representative cycles in lead II, and stimulus-to-atrial intervals are shown at their respective leads. Abbreviations as in Figure 3.
from retrograde conduction. Nonetheless, a simple additional maneuver, such as withdrawing the pacing catheter slightly to obtain deliberate atrial capture, invariably shortens the stim-atrial interval unless atrial capture was already inadvertently present. A minimum 20-ms change in stim-atrial interval in this study confirmed direct atrial pacing (Figure 5). Although a stim-PCS interval <60 ms predicted direct atrial capture in this relatively small series, any fixed measurement is likely to be fallible in the border zones, and thus, the comparison of intervals before and after deliberate direct atrial pacing would be expected to be more reliable.

Additionally, the ROC curves suggest that a single stim-PCS cutoff value is not both highly specific and highly sensitive and, thus, cannot be used; a stim-HRA cutoff value also is not both highly sensitive and highly specific. However, a single value of <85 ms is highly specific only for stim-HRA intervals (but not sensitive) and highly sensitive only for stim-PCS intervals (but not specific) to identify atrial capture. Therefore, an absolute value does not exist that identifies atrial capture with an accuracy of 100% because of the overlap zone, and this single value (85 ms) is of limited use.

Limitations
The use of fixed measurements of stim-atrial intervals is limited by the small number of patients studied and potentially by some variability in the catheter positioning determined fluoroscopically in conjunction with morphology of the electrograms. The positions, nonetheless, are relatively standard, and the variations would not be expected to be great. Additionally, the observation of the decrease in the stim-atrial interval with deliberate atrial capture was observed in every patient acting as their own controls, providing confidence in the reliability of the finding.

Conclusions
The stim-PCS and stim-HRA intervals can be used to monitor for inadvertent atrial capture during para-Hisian pacing. A stim-PCS interval <60 ms (or stim-HRA <70 ms) is observed only with direct atrial capture, and a stim-PCS >90 ms (or stim-HRA >100 ms) is observed only in the absence of atrial capture. An overlap zone between these values exists where atrial capture cannot be excluded or confirmed. A change of stim-atrial interval of 20 ms using a small catheter adjustment to lose or obtain atrial capture deliberately reliably ensures that inadvertent atrial capture had not occurred.

Acknowledgments
We thank our meticulous electrophysiology technicians, Mr Paul Purves and Ms Ellie Hogg, for their dedication to all the research protocols.

Disclosures
None.

References

CLINICAL PERSPECTIVE
The para-Hisian pacing maneuver is very useful in clinical electrophysiology, but care must be taken to avoid technical and interpretative pitfalls. Inadvertent atrial capture during the maneuver may give the erroneous impression of retrograde conduction over a septal accessory pathway in the absence of an accessory pathway or retrograde conduction over the AV node in the presence of an accessory pathway. Intuitively, direct atrial capture should give a very-short stimulus-to-atrial interval. A stimulus-to-atrial interval at the proximal coronary sinus of <60 ms (or <70 ms at the high right atrium) is observed only with direct atrial capture. A stimulus-to-proximal coronary sinus interval of >90 ms (or >100 ms at the high right atrium) is observed only in the absence of atrial capture. An overlap zone between these values exists where atrial capture cannot be excluded or confirmed. A change of stimulus-to-atrial interval of 20 ms using a small catheter adjustment to lose or obtain atrial capture deliberately reliably ensures that inadvertent atrial capture has not occurred.
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