Determination of Inadvertent Atrial Capture during Para-Hisian Pacing

Running title: Obeyesekere et al.; Atrial Capture during Para-Hisian Pacing

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Abstract:

**Background** - Inadvertent capture of the atrium will lead to spurious results during para-Hisian pacing. We sought to establish if 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±18ms) compared to H+V (121±27ms, p<0.001) or V capture alone (174±38ms, p<0.001). The mean stim-PCS interval was significantly shorter with atrial capture (51±16ms) compared to H+V (92±22ms, p<0.001) or V capture alone (146±33ms, p<0.001). A stim-PCS <60ms (stim-HRA <70ms) was observed only with atrial capture. A stim-PCS >90ms (stim-HRA >100ms) was only observed in the absence of atrial capture. A stim-HRA of <85ms was highly specific and stim-PCS of <85ms was highly sensitive at identifying atrial capture. Stim-HRA intervals of 75-97ms and stim-PCS intervals of 65-88ms 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 20ms 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, observed in 20/31 (65%) patients.

**Conclusions** - Stimulus to PCS/HRA intervals can be utilized to monitor for inadvertent atrial capture during para-Hisian pacing. A stim-PCS <60ms (or stim-HRA <70ms) and stim-PCS >90ms (or stim-HRA >100ms) were only observed 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.

**Key words:** electrophysiology test; tachyarrhythmia or tachyarrhythmias; His; para-Hisian pacing
Introduction

Para-Hisian pacing (1) is a commonly used electrophysiological (EP) maneuver to help distinguish retrograde septal accessory pathway (AP) conduction versus that over the normal AV conduction system. During this maneuver, the correct diagnosis is dependent 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 is infrequently observed (2)). Inadvertent capture of the atrium during this maneuver may lead to spurious results (Figures 1 and 2). This is not always evident as the pacing electrodes are saturated during pacing and the proximal pair may not be adequate to define the stimulus to atrial interval (stim-atrial) 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 if conduction times from the stimulus to atrial recording sites in either standard high right atrial (HRA) position or near the orifice of the coronary sinus (PCS) were sufficiently short to identify direct inadvertent atrial capture, as opposed to conduction to the atria via the anomalous or normal AV conduction systems during the para-Hisian pacing maneuver.

Methods

We prospectively analyzed intracardiac recordings in patients undergoing an electrophysiology study (EPS) 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 EPS for documented or suspected supraventricular tachycardia (SVT) were included in the study. None had anterograde pre-
excitation. Patients with prior ablation, with an implanted cardiac device or structural heart
disease were excluded. All patients had medications administered for SVT stopped at least 5 half
lives prior to the procedure. All patients provided written informed consent.

At EPS, 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 bipoles at the CS ostium). Surface
electrocardiograms (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 500Hz and measured using online calipers at a sweep
speed of 100mm/s.

Para-Hisian pacing was undertaken from the proximal and/or 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 20V output and 2ms pulse width at rates faster than
the sinus rate. At this output, the pacing spike typically captured the atrium and para-Hisian
ventricular myocardium and His bundle. The His catheter was withdrawn slightly to the atrium
to confirm atrial capture and then advanced towards the ventricle to ensure loss of atrial capture
while maintaining para-Hisian His and ventricular myocardial capture. Finally, pacing output
was then gradually reduced to lose His capture and obtain para-Hisian ventricular capture alone.

The stimulation to atrial electrogram interval at the proximal coronary sinus (stim-PCS) and high
right atrium (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 SR) were utilized 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. Stimulation to atrial interval change (at HRA and PCS) from atrial capture to H+V capture was calculated for each patient. QRS morphology was assessed visually and by measuring QRS widths associated with SR, atrial capture, H+V capture and V capture.

Statistics
Continuous variables are expressed as mean ± SD. Continuous variables were compared by use of a two-tailed Student’s t-test. Atrial capture was compared to H+V capture and atrial capture was also compared to V capture alone. Receiver operator characteristic (ROC) curves were constructed to determine stim-PCS and stim-HRA cut-offs to distinguish between atrial capture and atrial non-capture. P-values <0.025 were considered significant to correct for multiple comparisons. The authors had full access to the data and take full responsibility for its integrity. All authors have read and agree to the manuscript as written.

Results
Thirty-one patients, 13 men and 18 women, aged 48±19 years (median 46, 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±18ms, range 37ms to 97ms) compared to H+V (mean 121±27ms, p<0.001), range 75ms to 170ms) or V capture alone (mean 174±38ms, p<0.001, range 112ms to 250ms). The mean stim-PCS interval was significantly shorter with atrial capture (mean 51±16ms, range 29ms to 88ms) compared to H+V (mean 92±22ms, p<0.001, range 65ms to 140ms) or V capture alone (mean 146±33ms, p<0.001, range 83ms to 228ms) – Figure 3.

A stim-PCS < 60ms was only observed with atrial capture and a stim-PCS > 90ms was only observed in the absence of atrial capture. Similarly a stim-HRA < 70ms was only observed with atrial capture and stim-HRA > 100ms was only observed in the absence of atrial capture. The area under the ROC curve for identifying atrial capture by stim-PCS was 0.9435 (95% CI, 0.8872 to 0.9999; P<0.001) and for stim-HRA was 0.9662 (95% CI, 0.9276 to 0.9999; P<0.001) (Figure 4 & Table 1). A stim-HRA interval <85ms 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 <85ms 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 (i.e., stim-HRA interval between 75ms and 97ms and stim-PCS interval between 65ms and 88ms) where atrial capture could not be determined for certain merely by measuring stim to atrial intervals (Figure 3). A mean stim-HRA interval prolongation of 50±18ms (range 23ms to 80ms) and stim-PCS interval prolongation of 41±17ms (range 21ms to 82ms) 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 20ms when the catheter was advanced to eliminate atrial capture and obtain only H+V capture during the para-Hisian maneuver (Figure 1). Alternatively all patients demonstrated a stim-atrial interval shortening of at least 20ms when the catheter was pulled back to regain atrial capture (Figure 5).

The QRS morphology and width were not useful to confirm/exclude atrial capture due to concurrent capture of para-Hisian V or H+V. The minimal QRS width change from atrial capture (i.e., pure A or A+H+V or A+V) to atrial non-capture (i.e., V or V+H capture) ranged from 0ms to 83ms (median 22ms, mean 23±18ms). Furthermore, in 20/31 (65%) patients the QRS width associated with atrial capture was within 10ms to that associated with ventricular capture (Figure 1 & 2) or H+V capture.

Discussion

The major findings of the current study are the following: 1. A stimulus to atrial interval less than 60ms at the PCS (or stim-HRA < 70ms) is only observed with direct atrial capture. 2. A stim-PCS >90ms (or stim-HRA >100ms) is only observed in the absence of atrial capture. 3. A shortening of stimulus to atrial interval at the CS orifice or at the HRA by 20ms 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 stimulus to atrial interval. 5. In any single patient, pure ventricular capture resulted in the longest stim-atrial interval with the widest QRS. To our knowledge this is the first manuscript 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 (3,4). 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 stimulus to atrial interval. This may be difficult to recognize as the most useful electrogram to assess atrial capture is that in the pacing channel (i.e., 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 due to poor contact and is itself distant from the site of interest. In addition, the pacing catheter may also capture the ventricular muscle and/or His bundle, which further makes the atrial electrogram at the pacing site difficult to interpret.

We initiated this study with the hypothesis that the stimulus to atrial interval measured at the CS orifice or HRA should be shortest with direct atrial capture compared to retrograde conduction via an accessory pathway or the His bundle, and an absolute value may exist to characterize atrial capture. Indeed, direct atrial capture was characterized by very short intervals. Stimulus to PCS intervals <60ms or stimulus to HRA < 70ms were only observed with direct atrial capture (specificity 100%), while intervals longer than 90ms at the PCS or 100ms at the HRA were only observed in the absence of direct capture (specificity 100%). Outside of these limits, it was not possible to reliably distinguish direct atrial capture from retrograde conduction. Nonetheless, a
simple additional maneuver such as withdrawing the pacing catheter slightly to obtain deliberate atrial capture invariably shortens the stimulus to atrial interval unless atrial capture was already inadvertently present. A minimum 20ms change in stim-atrial interval in this study confirmed direct atrial pacing (Figure 5). Although a stimulus to atrial interval at the PCS less than 60ms 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 cut off value is not both highly specific and highly sensitive and thus cannot be used (and neither is a stim-HRA cut off value both highly sensitive and specific). However a single value of <85ms 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% due to the overlap zone, and this single value (85ms) is of limited use.

**Limitations**

The use of fixed measurements of stimulus to 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 are nonetheless 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 control providing confidence in the reliability of the finding.

**Conclusion**

The stimulus to PCS/HRA interval can be utilized to monitor for inadvertent atrial capture during para-Hisian pacing. A stimulus to atrial interval at the PCS of <60ms (or < 70ms at the HRA) is only observed with direct atrial capture and a stim-PCS > 90ms (or stim-HRA > 100ms) is only observed in the absence of atrial capture.

An overlap zone between these values exists where atrial capture cannot be excluded/confirmed. A change of stimulus to atrial interval of 20ms using a small catheter adjustment to lose or obtain atrial capture deliberately, reliably ensures that inadvertent atrial capture had not occurred.

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

**Conflict of Interest Disclosure:** None.

**References:**


Table 1: Stim-HRA and stim-PCS test performance to identify atrial capture

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<th>Test</th>
<th>Cut off</th>
<th>Sensitivity</th>
<th>Specificity</th>
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<td>72ms</td>
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<td>100%</td>
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Figure Legends:

**Figure 1:** Para-Hisian pacing sequence. The 1st two panels reveal a stim-HRA and stim-PCS interval that remains constant with current reduction that resulted in widening of the QRS. This might be mistaken to indicate the presence of a septal accessory pathway except that stimulus to atrial at the PCS is less than 60ms indicating direct atrial capture (see text). Slight repositioning to lose atrial capture in the 3rd panel reveals His capture with prolongation of the stimulus to
atrial interval and further prolongation when His capture is lost, confirming absence of a septal AP. Stimulus to atrial intervals in milliseconds are shown at their respective leads.

**Figure 2**: Para-Hisian pacing sequence. Current is reduced from the first to second panel with widening of the QRS suggesting loss of His capture and no septal AP. However, the stimulus to atrial interval at the PCS in the first panel is only 55ms, confirming atrial capture. Slight repositioning more distally again narrowed the QRS (3rd panel) suggesting His capture but the stimulus to atrial interval at the PCS is now 111ms, confirming the presence of a septal accessory pathway without atrial capture. The last panel was also observed during para-Hisian pacing – a wide beat with concurrent atrial and ventricular capture, which could also lead to spurious interpretation if not recognized as atrial capture. Stimulus to atrial intervals in milliseconds are shown at their respective leads.

**Figure 3**: Scatter plot demonstrating stim-atrial intervals during atrial capture, His plus para-Hisian ventricular capture and pure ventricular capture.

**Figure 4**: Receiver operating curves for stim-PCS and stim-HRA to identify atrial capture.

**Figure 5**: Para-Hisian pacing example. The catheter is initially in the region of interest and the QRS duration and morphology of the first paced cycle suggest pure ventricular capture. Nonetheless, the stimulus to atrial intervals are relatively short and atrial capture cannot be ruled out. With slight increase in current, the QRS narrows suggesting His and para-His capture but the stimulus to atrial interval remains short. Slight catheter pullback (3rd cycle) results in shortening of the stimulus to atrial interval, confirming atrial capture, in addition to concurrent His and para-Hisian capture. Thus, the 1st cycles demonstrate the presence of a septal accessory pathway with ruling out of inadvertent atrial capture. The QRS widths are provided under their representative cycles in lead II and stimulus to atrial intervals are shown at their respective leads.
Stim-PCS ROC area 0.943

Stim-HRA ROC area 0.966
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