Usefulness of Unipolar Electrograms to Detect Isthmus Block After Radiofrequency Ablation of Typical Atrial Flutter

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**Background**—RS morphology of the unipolar electrogram is associated with propagation of the wave front through the exploring electrode, whereas positive uniphasic (R) unipolar electrograms are characteristic of the end of activation.

**Methods and Results**—Unipolar electrograms were recorded in 45 consecutive patients with atrial flutter who were undergoing radiofrequency ablation (RFA). Bidirectional cavotricuspid isthmus (CTI) block was achieved in 44 patients. The unipolar electrogram obtained before RFA at the low anterolateral right atrium during coronary sinus pacing changed from RS, rS, or QS to R or Rs in all patients after clockwise CTI block was obtained. The morphology of unipolar electrograms recorded close to the coronary sinus during pacing from the low anterolateral right atrium changed from RS or rS to R or Rs in all but 4 patients after counterclockwise CTI block. In the patient in whom CTI block was not achieved, the RS morphology of the unipolar electrogram remained unchanged. In 18 patients, the results of the RFA were assessed with only the unipolar electrogram. The unipolar electrogram correctly predicted 100% and 89% of the cases of clockwise and counterclockwise CTI block, respectively.

**Conclusions**—The creation of CTI block is associated with an easily detectable loss of negative components and development of an R or Rs pattern of the unipolar electrogram recorded close to the ablation line while pacing at the opposite side of the CTI. *(Circulation. 2000;102:3080-3085.)*

**Key Words:** atrial flutter  electrophysiology  ablation

The aim of radiofrequency catheter ablation (RFA) for atrial flutter (AFL) is to create a complete and stable bidirectional cavotricuspid isthmus (CTI) block. Although other methods have been proposed to detect the creation of CTI block, meticulous mapping of the tricuspid annulus (TA) before and after RFA is still the technique of choice. The purpose of our study was to investigate the usefulness of unipolar recordings to assess bidirectional CTI block.

Spach et al showed that conduction along the longitudinal axis of the fibers in cardiac muscle produces a characteristic biphasic (RS) unipolar electrogram, whereas positive unipolar (R) electrograms are characteristic of termination of the activation wave front.

We hypothesized that an RS unipolar electrogram recorded in the CTI area would be predictive of conduction, whereas a dominant R unipolar electrogram could be indicative of CTI block (Figure 1).

**Methods**

**Study Population**
The study population consisted of 45 consecutive patients (mean age 63±10 years, 76% males) referred for catheter ablation of typical AFL. Structural heart disease was present in 26 patients: hypertensive cardiomyopathy (5 patients), ischemic heart disease (7 patients), cor pulmonale (9 patients), valvular heart disease (4 patients), and congenital heart disease (1 patient). Two patients had previously undergone an unsuccessful attempt at catheter ablation of the AFL.

**Electrophysiological Evaluation and Recordings**
All patients gave informed written consent. Antiarrhythmic drug therapy was discontinued for at least 5 half-lives in all but 7 patients (amiodarone in 4 patients and a I-C– class antiarrhythmic drug in 3 patients).

Catheters were positioned around the TA (20 electrodes, Halo, Cordis Webster, Inc), at the coronary sinus ostium (CSos; Marinr [Medtronic], with a 4-mm-tip electrode, and 2-5-2– or 2-2-250 –mm interelectrode spacing), and at the His region (Josephson, Bard Angiomed).

At least 10 bipolar or unipolar simultaneous intracardiac electrograms were recorded with 1 surface ECG lead (II or aVF), at paper speeds of 100 and 200 mm/s (Midas, Hellige Biomedical). Unipolar electrograms were recorded with the exploring electrode connected to the positive pole and a catheter electrode located at the inferior vena cavae connected to the negative pole. The gain was set at 1 to 2 mV/cm and the filtering at 0.05/2500 Hz. Bipolar electrograms were recorded with a gain amplification of 0.5 to 1 mV/cm and filtered at 30/500 Hz. The ablation procedure was always performed...
The definitions used of clockwise CTI block, rate-dependent clockwise CTI block, counterclockwise CTI block, and rate-dependent counterclockwise CTI block have been described elsewhere.14

Radiofrequency Ablation
A quadrupolar 8-mm-tip electrode ablation catheter with temperature control (Blazer T, EP Technologies) was inserted through a right femoral sheath. The CTI linear lesion was made sequentially during CSos pacing, with point-by-point ablation from the ventricular aspect of the TA to the inferior venae cavae. Radiofrequency (RF) energy (550 kHz unmodulated sine wave output up to 100 W) was delivered through a generator (EP Technologies) with a temperature setting of 70° for 30 seconds at each point with no movement of the catheter.

The end point was bidirectional CTI block and noninducibility of isthmus-dependent Af by programmed stimulation that persisted for at least 30 minutes. In case of failure, additional RF applications were made over the previous line, with RF applied at the sites where large single bipolar electrograms were found.

Unipolar Electrogram Evaluation Protocol
We analyzed the morphology of unipolar electrograms before and after the first RF ablation line and after each additional RF application using the distal electrode of the ablation catheter. We tried to position the exploring catheter as close as possible to the ablation line but where it could still record a clearly visible atrial electrogram, before pacing from the opposite side. We were extremely careful in positioning the exploring electrode at the same place each time. This was verified by the morphology of the local ventricular electrogram and by anatomic landmarks in the same fluoroscopic (left anterior oblique, right anterior oblique, and posterior-anterior) projections, together with the relationship of the exploring catheter with the more stable catheters located at the His and CSos.

To evaluate the ability of unipolar electrogram morphology to guide the ablation procedure, for the last 18 patients, the bipolar recordings from the TA were initially hidden, and only the unipolar electrograms recorded from the distal electrode of the ablation catheter were used to assess CTI block. Once CTI conduction status was predicted by unipolar electrograms, the presence or absence of CTI block was confirmed by conventional TA mapping.

Definitions
The definitions used of clockwise CTI block, rate-dependent clockwise CTI block, counterclockwise CTI block, and rate-dependent counterclockwise CTI block have been described elsewhere.14

Unipolar Waveforms
The following definitions of unipolar waveforms were used:
- RS: One positive deflection followed by a negative deflection with an R/S ratio ≥ 1/3 and ≤ 3/1. The magnitude of the S wave was calculated with the line between the atrial and ventricular unipolar electrograms used as a reference. In case of doubt about the unipolar electrogram morphology due to overlapping of the atrial and ventricular unipolar electrograms, several maneuvers (carotid sinus massage, adenosine infusion, or atrial pacing) were performed to separate atrial from ventricular activity.
- rS: One small positive deflection (≥ 0.1 mV) followed by a negative deflection with an r/S ratio < 1/3.
- RS: One large positive deflection followed by a small negative deflection (≥ 0.1 mV) with an R/S ratio < 3/1.
- QS: Only 1 large negative deflection. Small positive deflections < 0.1 mV were not considered.
- R: Only 1 large positive deflection. Small negative deflections < 0.1 mV were not considered.

Interobserver Agreement
Two electrophysiologists analyzed 90 random and isolated unipolar electrograms and were asked to define unipolar electrograms and to predict the presence of CTI block.

Statistical Analysis
Statistical analysis was performed with JMP 3.0.1 statistical software (SAS Institute Inc, 1994). Data are reported as distributions and mean±SD values. Statistical comparisons for 2 groups were performed with the paired t test. A probability value < 0.05 was considered significant. To investigate the agreement among observers, the κ-statistic was calculated with the statistical program Systat 5.0 for Macintosh (Systat Inc.).

Results
After a median of 12±8 RF applications, bidirectional block of the CTI was achieved in 44 patients. In 1 patient, bidirectional conduction through the CTI was still present after 35 RF applications. In this patient, no further applications of RF current were delivered.

Unipolar Morphology and Clockwise CTI Conduction
At the beginning of the study, clockwise CTI conduction was observed in all patients. The unipolar electrogram obtained at the LALRA during pacing from the CSos was RS in 22 patients, rS in 20 patients, and QS in 3 patients.

After clockwise CTI conduction block was achieved, the unipolar electrogram recorded at the LALRA adjacent to the ablation line changed to R in 31 patients and to Rs in 13 patients (Figure 2). The interval between the stimulus artifact and the local atrial electrogram increased from 66±17 to 146±23 ms (P < 0.001). In the single patient without CTI block at the end of the procedure, the unipolar electrogram remained unchanged.

In patients with Rs at the chosen site after CTI block, we mapped the adjacent sites. In all patients, a monophasic R unipolar electrogram could be obtained by positioning the catheter close enough to the line of block. However, in most cases, the R wave was of low amplitude, presumably because...
of its proximity to the endocardial lesion. Conversely, by moving the exploring catheter away from the line of RF applications, we observed an increase in the amplitude of the negative component of the unipolar electrogram in all patients.

Unipolar Morphology and Counterclockwise CTI Conduction
At the beginning of the study, counterclockwise CTI conduction was present in all patients during LALRA pacing. The unipolar electrogram recorded at the septal aspect of the CTI during pacing from the LALRA was RS in 21 patients, rS in 23 patients, and QS in 1 patient.

After ablation, counterclockwise conduction block through the CTI was observed in all but 1 patient. The unipolar electrogram recorded at the septal aspect of the CTI during pacing from the LALRA was RS in 21 patients, rS in 23 patients, and QS in 1 patient.

Unipolar Morphology During Rate-Dependent Block
In 11 patients, we observed transient rate-dependent CTI block (clockwise CTI block in 11 patients and bidirectional CTI block in 3 patients) before persistent CTI block was obtained. These patients provided an opportunity for us to study the changes in unipolar electrogram morphology during a variable conduction status while maintaining the exploring catheter at exactly the same site. Clockwise CTI transient block was observed at a mean cycle of 375 ± 65 ms after RF attempts (Figures 3 and 4). In all these patients, we observed perfect concordance between the unipolar electrogram morphology and the appearance/disappearance of the CTI block. The unipolar electrogram was QS, rS, or RS before CTI block and always changed to R or Rs after CTI block. Although in most cases, the change in the unipolar electrogram morphology was sudden, we could observe a gradual change in 2 patients, with a progressive decrease of the S wave during the change from an RS to an R unipolar electrogram.

Unipolar Morphology and Conduction Delay
In 8 patients, conduction times through the CTI increased ≥10 ms in either the clockwise (6 patients) or counterclockwise (2 patients) direction during the course of the procedure. In these cases, changes in the unipolar electrograms remained predictive of conduction through the CTI despite the presence of a conduction delay (Figure 5).

Blinded Prospective Study
In the group of patients in whom the TA bipolar electrograms were initially hidden, the sensitivity, specificity, and positive
predictive values of recording an R or Rs unipolar electrogram at the LALRA for predicting clockwise CTI conduction block were 100%. The sensitivity, specificity, and positive predictive values of recording an R or Rs unipolar electrogram at the CSos were 89%, 100%, and 100%, respectively, for predicting counterclockwise CTI conduction block.

Interobserver Agreement
Agreement between observers was good when unipolar electrogram morphology was analyzed ($\kappa$-statistic 0.78) and very good when the observers had to decide, using only the unipolar electrogram, whether the CTI was blocked ($\kappa$-statistic 0.95).

Discussion
The present study shows the usefulness of recording unipolar electrograms to assess CTI conduction during RFA of AFL. In particular, CTI block is associated with an easily recognizable change in the morphology of unipolar electrograms when recorded close to the ablation line on the opposite side of the pacing site.

Significance of Unipolar Electrogram Morphologies
Spach et al.12,13 found that conduction along the longitudinal axis of the fibers in cardiac muscle produces a characteristic biphasic, smooth, unipolar waveform RS. In contrast, positive uniphasic unipolar R electrograms are characteristic of the end of propagation. Uniphasic unipolar R electrograms can also be observed at the point of collision of 2 wave fronts, and negative waveforms QS are recorded in the vicinity of the site of excitation onset.12,13 Since Spach et al described their findings, several studies have demonstrated the value of unipolar electrograms in localizing the site of origin of cardiac activation in patients with atrial or ventricular tachycardias and accessory AV pathways.15–18 In patients with AFL, unipolar recordings have only been used to characterize zones of slow conduction.19

Methods to Confirm CTI Block
In recent years, confirmation of CTI conduction block during pacing from the LALRA and CSos has become the preferred end point in RFA of AFL.4–9 This method requires detailed mapping of the CTI, tricuspid ring, and interatrial septum. However, even after meticulous mapping, doubts may still exist about the presence of complete CTI block. Because RF applications may slow the conduction velocity at the CTI, the site of collision can vary along the lateral wall of the right atrium (pacing from the CSos), mimicking CTI block.14 In addition, in some patients, conduction through the crista terminalis may produce simultaneous activation of the distal electrodes of the mapping catheter, despite CTI block.14,20 Thus, even when perfect stability of the catheters is achieved during the entire procedure, which is not easy due to the anatomy of the CTI, the classic TA mapping approach may have some limitations.21

Other investigators have tried to simplify the confirmation of CTI block. Double potentials separated by an isoelectric interval have been recognized as markers of local block.15 This method also requires meticulous mapping of the CTI, and difficulties in interpretation may exist because of the decrease in amplitude as a result of the RFA.

Figure 4. Tracings showing rate-dependent counterclockwise CTI block after transiently effective RFA application. During pacing from LALRA, conduction through CTI recovers after first paced beat, and unipolar electrogram changes from RS to R. Exploring catheter was located close to CSos. Only the change in the sequence MS-Abl denotes development of CTI block. Abbreviations as in Figure 2.

Figure 5. Unipolar electrogram behavior in presence of CTI slow conduction. A, Electrograms obtained during CSos pacing at 500 ms at beginning of electrophysiological study. Recordings are organized as in previous figures. Interval between stimulus artifact and local unipolar electrogram obtained with exploring catheter located just lateral to line of RF application is 50 ms. Morphology of unipolar electrogram is RS. Bipolar electrograms mapping lateral right atrium show CTI conduction. B, Immediately after RF application, interval increased to 90 ms but maintained rS unipolar electrogram morphology. After remaining electrograms were incorporated, we could appreciate slow conduction through CTI. C, After new RF application, interval increased to 190 ms with clear unipolar electrogram change to R. CTI block was confirmed by adding the remaining bipolar electrograms. Abbreviations as in Figure 2.
Unipolar Recordings and CTI Block

The rationale of our study was to assess conduction across the CTI without needing a detailed mapping of this region, given that unipolar electrograms can detect not only local but also distant activity. In accordance with our hypothesis, pacing from each side of the CTI before ablation resulted in an R, rs, or QS pattern on the opposite side of the CTI. An S wave is expected, because the propagated wave front passes through the CTI and moves away from the exploring electrode. After CTI block, the paced wave front has to go around the TA before it reaches the exploring electrode, located at the other side of the line of block. Therefore, a clear change in the unipolar electrogram is expected (from QS, rs, or RS to R or Rs) because the wave front now ends at or close to the exploring electrode. The relative voltage of the R wave is likely to depend on the amount of tissue that depolarizes within the CTI, as well as the distance of the recording electrode from this area.13 However, to observe the expected unipolar electrogram changes, the exploring catheter should be located in close proximity to the line of block. We observed that if the exploring catheter was separated from the line of block, activation of the area of tissue between the exploring electrode and the line of block could generate an S wave of sufficient voltage to result in an RS unipolar electrogram.

In 4 patients, counterclockwise block did not result in a lack of S wave at the septal side of the CTI. The reason for this is not totally clear to us. Theoretically, an oblique ablation line could produce an RS complex in the presence of CTI block. It is also conceivable that if the CTI line of block is made close to the septum, when the exploring electrode is positioned at the septal side of the line of block, it could record left atrial activation propagating away from it, thus inscribing a significant S wave.

Unipolar Recordings and Incomplete CTI Block

The unipolar electrogram did not change significantly in our study with the presence of incomplete CTI block (after a failed RF line) compared with the unipolar electrogram recorded before the ablation attempt. This was not unexpected, because in case of incomplete block, independently of the location of the gap, the wave front crossing the CTI (sometimes with a prolonged conduction time) should pass through the exploring electrode, generating a propagation wave front that moves away from it. This seems to be an important advantage of unipolar electrograms, because they record relatively distant activity. Thus, unipolar electrograms seem to be able to distinguish between CTI block and slow conduction through the CTI.

Simplification of the Procedure

A possible role of unipolar electrogram recordings could be simplification of the ablation procedure in patients with AFI. We have demonstrated in 18 patients that the presence or absence of bidirectional CTI block can be diagnosed solely on the basis of the unipolar electrogram. This represents an initial attempt to simplify the CTI ablation procedure to enable just 2 catheters to be used (one for stimulation and the ablation catheter for unipolar electrogram recording). It is our experience that it is extremely unusual to produce isolated unidirectional counterclockwise block during the ablation procedure. Thus, a possible strategy could be to test conduction routinely in the clockwise direction with unipolar electrograms, because they are completely reliable for this purpose. Once counterclockwise block has been achieved, clockwise conduction could be tested with unipolar electrograms. If R or Rs morphology is observed, no further testing would be required, because this observation is a reliable predictor of block. However, in the 10% with RS morphology, assessment of counterclockwise conduction in the conventional fashion with multiple bipolar recording would be required.

Study Limitations

One limitation of our study is that we cannot be completely sure that the sites where we recorded the unipolar electrograms before and after CTI block were exactly the same. Thus, could minor modifications in the electrode location justify the changes in unipolar electrogram morphology? Two findings in our study make this unlikely. Before CTI block, despite exploration of multiple sites, we were not able to observe unipolar electrograms with R or Rs morphology during pacing from the LALRA or from the CSos in any patient. In addition, the observation of a rate-dependent block of the CTI gave us an extraordinary opportunity to appreciate the changes in morphology of the unipolar recordings at the same site when CTI block developed.

Theoretically, conduction velocity through the CTI could be so slow as to result in collision of the 2 wave fronts close to the RF line. In such a situation, the unipolar electrogram would be misleading, because collision of wave fronts produces an R-wave pattern. However, this situation would not be recognized by the bipolar recordings either, because activation of the lateral right atrial wall would be craniocaudal.

We used an 8-mm electrode to record unipolar electrograms. Because we have not systematically studied other electrode sizes, we are not sure whether our results can be applied to the use of different ablation catheters.

Clinical Implications

The present study demonstrates for the first time the usefulness of unipolar electrograms to assess CTI block. The changes observed in unipolar electrograms on the other side of the line of RF application during pacing from the CSos and from the LALRA may differentiate the presence of conduction block from slow conduction through the CTI. Thus, unipolar electrograms could be used to simplify the procedure to estimate conduction status through the CTI by using only 2 catheters for RF ablation of common AFI.

References

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