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Pulmonary Vein Isolation: Comparison of Bipolar and Unipolar Electrograms at Successful and Unsuccessful Ostial Ablation Sites

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Electrogram Analysis. ***Introduction:*** **No prior studies have quantitatively analyzed the characteristics of bipolar or unipolar electrograms that may be helpful in identifying successful ostial ablation sites in patients with atrial fibrillation undergoing segmental pulmonary vein isolation.**

Methods and Results: **The characteristics of bipolar and unipolar electrograms recorded at 185 successful and 120 unsuccessful ostial pulmonary venous ablation sites were analyzed in 21 patients with atrial fibrillation. A decapolar Lasso catheter was positioned near the ostia of the pulmonary veins, and a conventional ablation catheter was used to deliver radiofrequency energy at individual ostial sites where pulmonary vein potentials were recorded. With both bipolar and unipolar recordings, the only timing parameter that distinguished successful from unsuccessful ostial ablation sites was the timing of the electrogram recorded by the ablation catheter relative to the earliest pulmonary vein potential recorded by the Lasso catheter. With both bipolar and unipolar recordings, electrograms demonstrated a larger amplitude at successful than at unsuccessful ablation sites. Unipolar electrograms had a steeper intrinsic deflection at successful than at unsuccessful ostial ablation sites. The morphologies of the unipolar electrograms recorded by the ablation catheter and by the contiguous electrode of the Lasso catheter usually were identical.**

Conclusion: **In patients undergoing segmental isolation of the pulmonary veins, unipolar recordings provide more information than bipolar recordings helpful in distinguishing successful from unsuccessful ostial ablation sites. Furthermore, unipolar recordings, but not bipolar recordings, allow accurate localization of the position of the ablation catheter relative to the electrodes of the Lasso catheter.**
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atrial fibrillation, pulmonary vein, unipolar electrogram

Introduction

Segmental isolation of the pulmonary veins may be effective in eliminating atrial fibrillation.[1,2] This technique for pulmonary vein isolation has been guided by pulmonary vein potentials recorded near the ostia of the pulmonary veins. However, there has been no detailed or quantitative analysis of the electrogram characteristics at successful and unsuccessful ablation sites. Furthermore, the relative value of bipolar and unipolar recordings as a guide to selection of ablation sites has not been analyzed. Therefore, the purpose of this study was to compare bipolar and unipolar electrograms recorded at successful and unsuccessful ostial ablation sites in patients with paroxysmal atrial fibrillation undergoing segmental pulmonary vein isolation.

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Methods

Patient Characteristics

The subjects of this study were 21 patients with drug-refractory paroxysmal atrial fibrillation who underwent segmental isolation of the pulmonary veins. There were 16 men and 5 women (mean age 48 ± 13 years). Mean duration of symptomatic atrial fibrillation was 3.4 ± 2.4 years, and mean number of symptomatic episodes per month was 16 ± 11. One patient had coronary artery disease, 1 had hypertension, and the remaining 19 patients had no structural heart disease. Echocardiography demonstrated mean left ventricular ejection fraction of 0.58 ± 0.06 (range 0.39 to 0.70) and mean left atrial diameter of 39 ± 5 mm (range 33 to 48).

Electrophysiologic Study Protocol

Therapy with antiarrhythmic drugs was discontinued at least 48 hours before the procedure. After informed consent was obtained, right femoral venous access was obtained and a quadripolar electrode catheter was positioned in the coronary sinus. Transseptal catheterization was performed under guidance of intracardiac echocardiography. A 7-French decapolar ring catheter with 1-mm electrodes spaced at intervals of 4.5 or 6.0 mm (Lasso; Biosense Webster, Inc., Diamond Bar, CA, USA) and a 7-French quadripolar ablation catheter with a 4-mm distal electrode, embedded thermistor, electrode spacing of 2-5-2 mm, and deflectable tip

(EP Technologies Inc., San Jose, CA, USA) were inserted into the left atrium. Heparin was administered as needed to maintain an activated clotting time of 250 to 350 seconds.

ECG leads and intracardiac electrograms were recorded digitally (EPMedSystems, Inc., Mt. Arlington, NJ, USA). Pacing was performed with a stimulator (model EP-3 Clinical Stimulator; EPMedSystems) at twice diastolic threshold and pulse width of 2 msec.

Ten bipolar electrograms were recorded simultaneously with 10 pairs of adjacent electrodes of the Lasso catheter and with the distal pair of electrodes of the ablation catheter. The bandpass settings for the bipolar recordings were 30 to 500 Hz. An indifferent electrode positioned on the right thigh was used for unipolar recordings. Unipolar electrograms were recorded with each of the 10 electrodes of the Lasso catheter and with the distal electrode of the ablation catheter. The bandpass settings for the unipolar recordings were 0.05 to 200 Hz.

Mapping and Radiofrequency Catheter Ablation

In all cases, mapping and catheter ablation were performed during sinus rhythm or atrial pacing. Tansthoracic cardioversion was required to restore sinus rhythm in 13 patients, and either ibutilide or amiodarone administered intravenously was needed to prevent immediate recurrences of atrial fibrillation in four patients. Segmental isolation of the left superior, right superior, and left inferior pulmonary veins was attempted in each of the 21 patients. Successful isolation was achieved in 57 of these 63 pulmonary veins. Data from the right inferior pulmonary vein were not included in this study because the Lasso catheter usually could not be positioned within this vein and because isolation of this vein was attempted in only seven patients.

Pulmonary venous angiograms were performed to identify the location of the ostia. The Lasso catheter was positioned inside the pulmonary vein, within 5 mm of the ostium. During the procedure, only the bipolar electrograms were displayed. Pulmonary vein potentials were defined as deflections that had a sharp upstroke, duration <50 msec, and amplitude >0.05 mV, and that followed the atrial potential.[2-5] For optimal separation of pulmonary vein potentials from atrial electrograms, mapping and ablation in the left superior and inferior pulmonary veins were performed during distal coronary sinus pacing at a cycle length of 600 msec.[2]

Target sites for ablation were selected by identifying pulmonary vein potentials on high-speed recordings (150 to 200 mm/sec) that had equivalent or earlier activation relative to adjacent Lasso catheter recording sites. The ablation catheter always was positioned in close proximity and on the ostial side of the Lasso catheter.

To minimize the risk of pulmonary vein stenosis, radiofrequency ablation was performed using a maximum power of 30 W[1,6] and maximum electrode-tissue interface temperature of 52°C. The applications of energy were 30 to 60 seconds in duration. The endpoint for ablation was elimination of pulmonary vein potentials at all Lasso catheter recording sites. Successful pulmonary vein isolation was confirmed by complete entrance block into the pulmonary vein during induced atrial fibrillation.

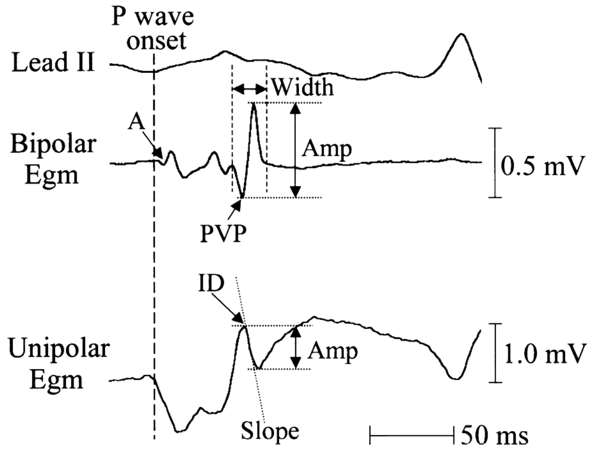

Figure 1. *Bipolar and unipolar recordings at an ostial ablation site in the right superior pulmonary vein. Shown are lead II, a bipolar electrogram, and a simultaneous unipolar electrogram recorded by the ablation catheter. Shown by arrows are the onset of the atrial component (A), the first deflection of the pulmonary vein potential (PVP), and the onset of the rapid negative intrinsic deflection (ID) of the unipolar electrogram. Amp = amplitude.*

Analysis of Electrograms

Quantitative analysis of the electrograms recorded by the ablation and Lasso catheters in 52 pulmonary veins was performed post hoc. Five of the 57 pulmonary veins that were isolated successfully were excluded from the analysis because radiofrequency ablation had been performed during atrial fibrillation. Measurements of electrogram amplitude, activation time, and duration were performed using electronic calipers. Analysis of bipolar electrograms consisted of the following measurements: interval from the stimulus (for the left pulmonary veins) or P wave onset on surface ECG (for the right superior pulmonary vein) to the first deflection of the pulmonary vein potential; interval from the onset of the atrial electrogram to the first deflection of the pulmonary vein potential; number of deflections in the pulmonary vein potential; width of the pulmonary vein potential; and maximum amplitude of the pulmonary vein potential (Fig. 1). The timing of the first deflection of the pulmonary vein potential recorded by the ablation catheter relative to the earliest pulmonary vein potential recorded by the Lasso catheter also was measured. In addition, the morphologies of the bipolar electrograms recorded by the ablation and Lasso catheters were compared. Electrogram onset was defined as the first deflection that had a slope >45° at a recording speed of 100 mm/sec.[7] Electrogram deflection was defined as a positive or negative deflection that had an amplitude ≥0.05 mV.

Analysis of the unipolar electrograms recorded by the ablation catheter included the following measurements: interval from the stimulus (for the left pulmonary veins) or P wave onset (for the right superior pulmonary vein) to the onset of the intrinsic deflection; interval from the onset of the atrial electrogram to the onset of the intrinsic deflection; and amplitude and slope of the intrinsic deflection whenever its amplitude was >0.2 mV (Fig. 1). The intrinsic deflection was defined as the rapid negative deflection of the unipolar electrogram.[8] Amplitude of the intrinsic deflection was measured from the nadir to the peak of the deflection. In

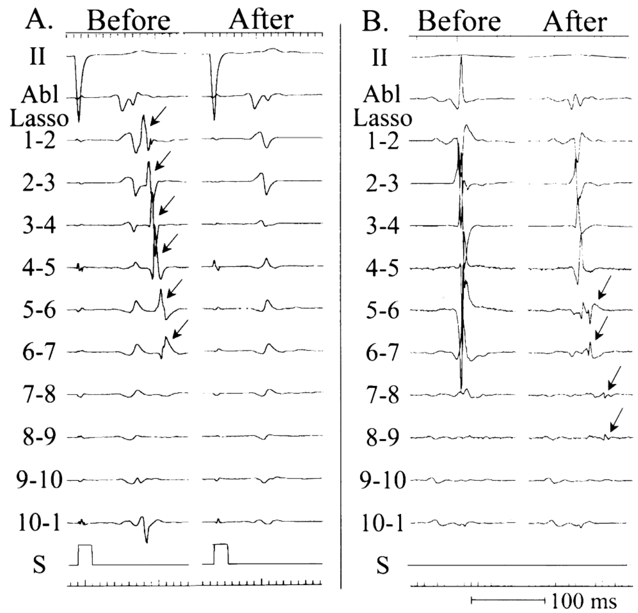

Figure 2. *Example of criteria for successful ablation sites. Shown are lead II, a bipolar electrogram recorded by the ablation catheter (Abl), 10 bipolar electrograms recorded by the Lasso catheter, and the stimulus (S) channel, before and after an application of radiofrequency energy. (A) Successful ablation site (in a left superior pulmonary vein) at which an application of radiofrequency energy resulted in elimination of pulmonary vein potentials (arrows) at ≥1 Lasso catheter recording sites. (B) Successful ablation site (in a right superior pulmonary vein) at which an application of radiofrequency energy resulted in delay of pulmonary vein potentials (arrows) by ≥10 ms at ≥2 Lasso catheter recording sites.*

addition, the morphologies of the unipolar electrograms recorded by the ablation and Lasso catheters were compared. The timing of the unipolar electrogram recorded by the ablation catheter relative to the unipolar Lasso catheter electrogram that had the same morphology was measured.

The bipolar and unipolar electrograms recorded at 185 successful ablation sites were compared with the corresponding electrograms recorded at all of the 120 unsuccessful ablation sites. A successful ablation site was defined as a site at which an application of radiofrequency energy resulted in either elimination of a pulmonary vein potential at ≥1 Lasso catheter recording sites (Fig. 2A), or delay of a pulmonary vein potential by ≥10 msec at ≥2 Lasso catheter recording sites (Fig. 2B). Electrograms recorded at unsuccessful ablation sites were included in this study only if the radiofrequency energy application had a minimum average power of 25 W, minimum temperature of 45°C, and minimum duration of 30 seconds.

Statistical Analysis

Continuous variables are expressed as mean ± 1 SD and were compared using Student's *t*-test. Categorical values were compared by Chi-square analysis. $P < 0.05$ was considered statistically significant.

Results

Bipolar Electrograms

Comparing successful and unsuccessful ablation sites, there was no significant difference in the interval from the stimulus or P wave to the first deflection of the pulmonary vein potential, or in the interval from the onset of the atrial electrogram to the first deflection of the pulmonary vein potential (Table 1). The timing of the pulmonary vein potential recorded by the ablation catheter relative to the earliest pulmonary vein potential recorded by the Lasso catheter was significantly earlier at successful sites than at unsuccessful sites (Fig. 3A; $P < 0.001$). The width of the pulmonary vein potentials at successful ablation sites (26 ± 8 msec) did not differ significantly from the width at unsuccessful ablation sites (25 ± 9 msec; $P = 0.6$). There also was no significant difference in the number of deflections in the pulmonary vein potentials between successful and unsuccessful ablation sites (2.7 ± 1.0 vs 2.5 ± 0.9; $P = 0.07$). However, the amplitude of the pulmonary vein potential was larger at successful sites than at unsuccessful sites (Fig. 3B; $P < 0.001$). The morphology of the electrograms recorded with the ablation catheter always differed from the morphology of the electrograms recorded with the Lasso catheter (Fig. 4).

Unipolar Electrograms

Comparing successful and unsuccessful ablation sites, there was no significant difference in the interval from the stimulus (or P wave onset) to the onset of the intrinsic deflection or in the interval from the onset of the atrial electrogram to the intrinsic deflection (Table 1). The timing of the intrinsic deflection recorded by the ablation catheter

TABLE 1

Comparison of Bipolar and Unipolar Electrograms at Successful and Unsuccessful Ostial Ablation Sites

	LSPV and LIPV			RSPV		
	Successful Sites	**Unsuccessful Sites**	**P Value**	**Successful Sites**	**Unsuccessful Sites**	**P Value**
Bipolar electrograms						
S(P)-PVP interval (msec)	81 ± 16	78 ± 18	0.2	59 ± 32	50 ± 15	0.09
A-PVP interval (msec)	36 ± 11	37 ± 16	0.9	40 ± 22	40 ± 11	0.8
Unipolar electrograms						
S(P)-ID interval (msec)	79 ± 15	77 ± 18	0.4	55 ± 21	51 ± 16	0.4
A-ID interval (msec)	33 ± 13	35 ± 17	0.6	36 ± 17	41 ± 15	0.1

Values are given as mean ± SD.

A-ID interval = interval from the onset of the atrial electrogram to the intrinsic deflection; A-PVP interval = interval from the onset of the atrial electrogram to the first deflection of the pulmonary vein potential; LIPV = left inferior pulmonary vein; LSPV = left superior pulmonary vein; RSPV = right superior pulmonary vein; S(P)-ID interval = interval from the stimulus (or P wave) to the onset of the intrinsic deflection; S(P)-PVP interval = interval from the stimulus (or P wave) to the first deflection of the pulmonary vein potential.

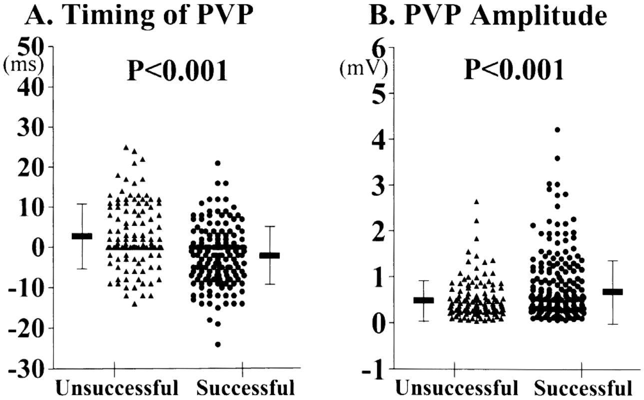

Figure 3. *(A) Timing of the pulmonary vein potential (PVP) recorded by the ablation catheter relative to the earliest pulmonary vein potential recorded by the Lasso catheter in bipolar electrograms. (B) Amplitude of the PVP recorded at successful and unsuccessful ablation sites in bipolar electrograms. Mean ± SD also are shown.*

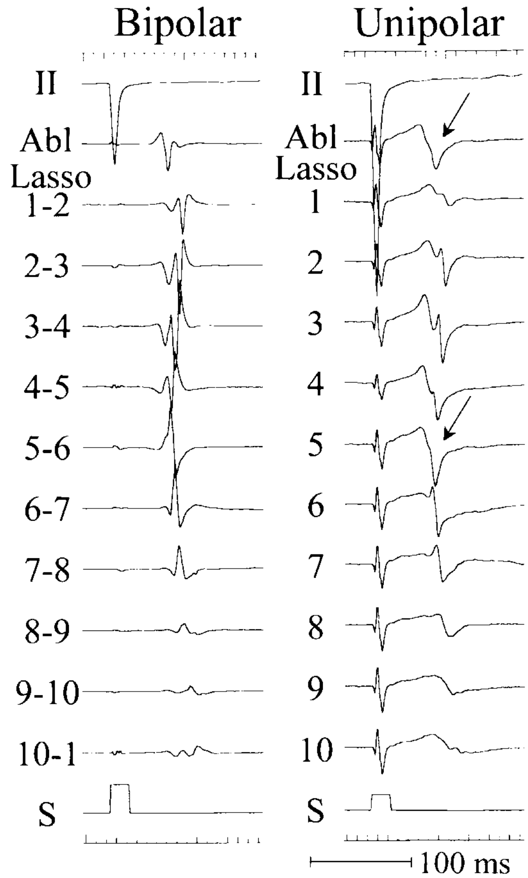

Figure 4. *Example of electrogram morphologies in bipolar and unipolar recordings of the same complex. Format as in Figure 2. The recordings were obtained in a left superior pulmonary vein during coronary sinus pacing at a cycle length of 600 ms. The morphology of the bipolar electrogram recorded by the ablation catheter does not match any of the bipolar electrograms recorded by the Lasso catheter. However, the morphology of the unipolar electrogram recorded by the ablation catheter is very similar to the morphology of the unipolar electrogram recorded by electrode 5 (arrow) of the Lasso catheter.*

relative to the intrinsic deflection recorded by the Lasso catheter that had the same morphology was significantly earlier at successful than at unsuccessful ablation sites (Fig. 5A; $P < 0.001$). The amplitude of the intrinsic deflection was significantly larger (Fig. 5B; $P < 0.001$), and the slope of the intrinsic deflection was significantly steeper at successful than at unsuccessful ablation sites (Figs. 5C and 6; $P < 0.001$).

A total of 245 unipolar electrograms (80%) recorded by the ablation catheter were very similar or identical in morphology to the unipolar electrogram recorded by the adjacent electrode of the Lasso catheter (Fig. 4). The unipolar electrograms recorded by the ablation catheter and by the adjacent electrode of the Lasso catheter more often were identical at successful ablation sites than at unsuccessful sites (90% vs 66 %; $P < 0.001$).

Sensitivity and Specificity of the Criteria

The sensitivity, specificity, and predictive accuracy of the electrogram criteria for identification of a successful ostial ablation site listed shown in Table 2.

Discussion

The quantitative analysis of electrograms performed in this study demonstrate the following findings in patients with atrial fibrillation undergoing segmental isolation of the pulmonary veins. (1) When using either bipolar or unipolar electrograms, the only timing parameter that distinguishes successful from unsuccessful ostial ablation sites is the timing of the electrogram recorded by the ablation catheter relative to the earliest pulmonary vein potential recorded by the Lasso catheter. (2) For both bipolar and unipolar electrograms, recordings at successful ablation sites demonstrate a larger amplitude than at unsuccessful ablation sites. (3) Unipolar electrograms have a steeper intrinsic deflection at successful than at unsuccessful ostial ablation sites. (4) The morphology of bipolar electrograms recorded with the ablation catheter never matched the morphology of the bipolar Lasso catheter electrograms, even when the two catheters were touching. (5) The morphology of the unipolar electrogram recorded by the ablation catheter usually matched the morphology of the unipolar electrogram recorded by the electrode of the Lasso catheter that it was closest to.

These findings indicate that unipolar electrograms have

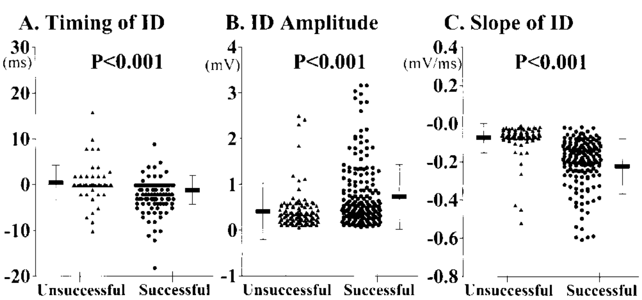

Figure 5. *(A) Timing of the intrinsic deflection (ID) recorded by the ablation catheter relative to the earliest pulmonary vein potential recorded by the Lasso catheter in unipolar electrograms. (B) Amplitude of the ID recorded at successful and unsuccessful ablation sites in unipolar electrograms. (C) Slope of the ID recorded at successful and unsuccessful ablation sites in unipolar electrograms. Mean ± SD also are shown.*

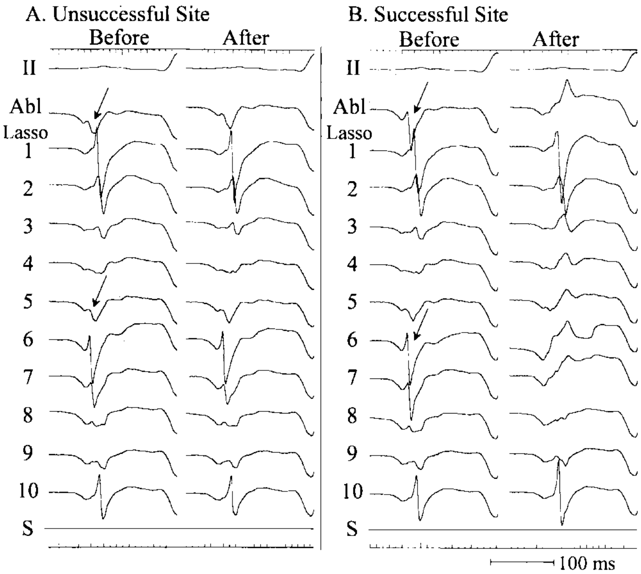

Figure 6. *Unipolar recordings from the right superior pulmonary vein during sinus rhythm. Format as in Figure 4. (A) Recording obtained at an unsuccessful ablation site. The morphology of the electrogram and the timing of the intrinsic deflection recorded by the ablation catheter are similar to those of the unipolar electrogram recorded by electrode 5 of the Lasso catheter (arrows). The slope of the intrinsic deflection and its amplitude are −0.07 mV/ms and 0.7 mV, respectively. (B) Recording obtained in the same vein, at a successful ablation site. The morphology of the electrogram and the timing of the intrinsic deflection recorded by the ablation catheter are similar to those of the unipolar electrogram recorded by electrode 6 of the Lasso catheter (arrows). The slope of the intrinsic deflection is steeper (−0.55 mV/ms) and the amplitude of the intrinsic deflection (2.1 mV) is greater at this successful ablation site than at the unsuccessful ablation site shown in panel A. Timing of the intrinsic deflection is the same as at the unsuccessful ablation site. Therefore, in this vein, the slope and amplitude of the intrinsic deflection were better discriminators of a successful ablation site than the timing of the intrinsic deflection.*

two advantages over bipolar electrograms in patients undergoing segmental pulmonary vein isolation. First, the intrinsic deflection of unipolar recordings provides a discriminant of successful and unsuccessful ostial ablation sites that is not available in bipolar electrograms. Second, comparison of the morphology of the unipolar electrograms recorded by the ablation and Lasso catheters usually allows accurate identification of the position of the ablation catheter relative to the electrodes of the Lasso catheter; in contrast, bipolar electrograms do not provide information on the position of the ablation catheter in the ostium.

Timing Intervals

Although activation times often are important when identifying ablation sites for targets such as accessory pathways,[9] in the present study, timing intervals were found to be of limited value. Timing parameters based on using the atrial pacing stimulus or P wave as the fiducial point did not distinguish successful from unsuccessful ostial ablation sites. Furthermore, although the timing of the pulmonary vein potential relative to the earliest pulmonary vein potential recorded by the Lasso catheter did statistically distinguish successful from unsuccessful ablation sites, the difference between the mean values at successful and unsuccessful sites was in the range of only 2 to 4 msec, which limits the practical value of this parameter in identifying effective ostial ablation sites.

There are two possible explanations for the failure of timing parameters to clearly distinguish successful from unsuccessful ablations sites. First, because there usually was >1 pulmonary vein fascicle at the ostia of the pulmonary veins[1] and because the different fascicles often had a wide range of conduction properties, timing intervals based on the atrial pacing stimulus or P wave as the fiducial points had a wide range of values that overlapped at successful and unsuccessful ablation sites. Second, the myofibrils that surround the pulmonary veins have a complex arrangement, with a longitudinal, oblique, or spiral course over the vein.[10,11] For the sake of catheter stability, the Lasso catheter was positioned approximately 5 mm in from the ostium. Therefore, if the ablation catheter was positioned at the ostium instead of at the position of the Lasso catheter, the timing of a pulmonary vein potential recorded by the Lasso catheter may not have accurately reflected the timing of that potential at the ostium.

TABLE 2

Sensitivity, Specificity, and Predictive Accuracy of Electrogram Criteria for Successful Ostial Ablation Sites

Criterion	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)
Bipolar electrograms				
Timing of pulmonary vein potential*				
<0 msec	50	75	75	49
< −1 msec	75	49	69	56
Amplitude of pulmonary vein potential ≥1.0 mV	29	90	82	45
Unipolar electrograms				
Timing of intrinsic deflection†				
<0 msec	33	91	85	47
< −1 msec	29	92	84	46
Amplitude of intrinsic deflection ≥1.0 mV	24	94	86	42
Slope of intrinsic deflection				
≤ −0.08 mV/msec	71	90	92	66
≤ −0.10 mV/msec	65	92	92	63

*Timing relative to earliest pulmonary vein potential recorded by Lasso catheter.
†Timing relative to earliest intrinsic deflection recorded by Lasso catheter.
NPV = negative predictive accuracy; PPV = positive predictive accuracy.

Intrinsic Deflection of the Unipolar Electrogram

The intrinsic deflection in a unipolar electrogram is largely independent of the effects of distant potentials and is indicative of local activation.[8] Furthermore, the steepness of the intrinsic deflection is related to proximity of the recording electrode to the target tissue.[8] This may explain why a steep intrinsic deflection in the unipolar electrogram differentiated successful and unsuccessful ablation sites in this study. It is likely that ablation sites that had the steepest intrinsic deflections were closest to the muscle fascicles that were being targeted. The information provided by the intrinsic deflection of the unipolar electrogram is not available in bipolar electrograms.

Electrogram Amplitude

The mean amplitudes of the bipolar and unipolar electrograms recorded at successful ablation sites were significantly greater than at unsuccessful ablation sites. As with the steepness of the intrinsic deflection, the larger bipolar and unipolar electrogram amplitudes at successful ablation sites probably were attributable to close proximity of the recording site to the underlying pulmonary vein fascicle.[8]

Electrogram Morphology

The 10 electrodes of the Lasso catheter arranged in a ring configuration provide positional reference points within the pulmonary vein. These positional reference points facilitate localization of the ablation catheter at ostial ablations sites. However, fluoroscopic determination of the position of the ablation catheter relative to the electrodes of the Lasso catheter may be imprecise, particularly in the absence of biplane fluoroscopy and when a high-magnification mode is not used.

The results of this study demonstrate that the morphology of the unipolar electrograms recorded with the ablation and Lasso catheters allows accurate localization of the ablation catheter without the use of fluoroscopy. In approximately 80% of unipolar recordings in this study, the morphology of the unipolar electrogram recorded with the ablation catheter was identical to the morphology of the unipolar electrogram recorded by the contiguous electrode of the Lasso catheter. Therefore, simple inspection of the unipolar electrograms recorded by the ablation Lasso catheters usually indicates the position of the ablation catheter relative to the 10 electrodes of the Lasso catheter. In the 20% of unipolar electrograms that did not resemble any of the unipolar electrograms recorded by the Lasso catheter, it is likely that this was attributable to a wider separation than usual between the electrodes of the ablation and Lasso catheters.

In contrast, regardless of proximity, the bipolar electrograms recorded by the ablation and Lasso catheters never had the same configuration. This may be explained by the different widths of the electrodes of the two catheters, different interelectrode distances, and different orientations of the bipoles within the pulmonary vein.

Limitations of Unipolar Electrograms

A limitation of unipolar recordings is their greater susceptibility to baseline wander and artifact. To minimize this problem, filter settings of 0.05 to 200 Hz were used for the unipolar recordings in this study, instead of the more conventional technique of using either unfiltered recordings or filter settings of 0.05 to 400–500 Hz.[8]

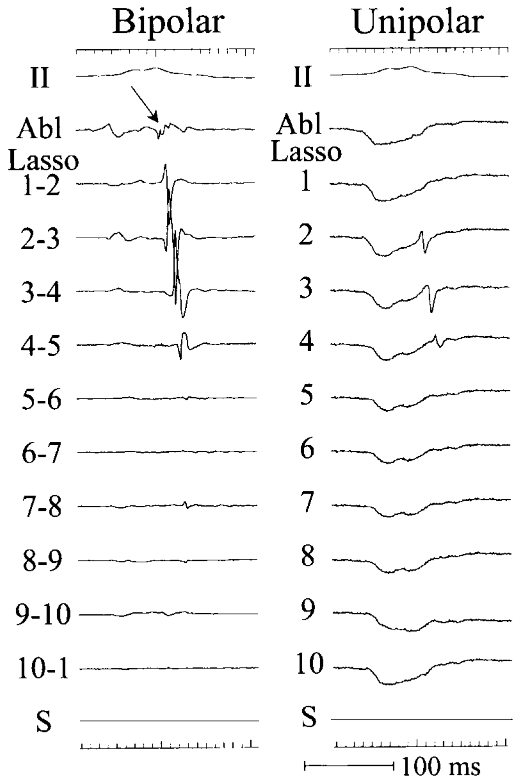

Figure 7. *Bipolar and unipolar recordings in a right superior pulmonary vein during sinus rhythm. Format as in Figure 4. A small pulmonary vein potential (arrow) is present in the bipolar recording but not in the unipolar recording.*

Another limitation of unipolar electrograms is their inability to provide useful information when the electrogram amplitude is small. In some cases, bipolar electrograms must be used because a small deflection may not be apparent in a unipolar recording (Fig. 7). However, in 91% of unipolar electrogram recordings in this study, the amplitude of the intrinsic deflection was $\geq$0.1 mV, and the intrinsic deflection was easily discernable.

Conclusion

Although successful segmental electrical isolation of the pulmonary veins is readily achieved using bipolar recordings as a guide for identification of ostial ablation sites, the results of this study suggest that the number of applications of radiofrequency energy required for a successful outcome and, therefore, the risk of complications, such as pulmonary vein stenosis, may be minimized by the use of unipolar recordings. The intrinsic deflection of the unipolar electrograms recorded near the ostia of the pulmonary veins may provide better discrimination between successful and unsuccessful ablation sites than various characteristics of bipolar electrograms. In addition, the unipolar electrogram morphology provides a convenient and accurate method for localization of the ablation catheter relative to the electrodes of the Lasso catheter, without the need for fluoroscopy. However, the unipolar electrograms were analyzed only in a post hoc fashion in this study, and a prospective study is needed to determine whether the use of unipolar electrograms facilitates segmental isolation of pulmonary veins.

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