Bipolar electrograms characteristics at the left atrial–pulmonary vein junction: Toward a new algorithm for automated verification of pulmonary vein isolation

Milad El Haddad, PhD,[*] Richard Houben, BSc,[†] Benjamin Berte, MD,[‡]
Frederic Van Heuverswyn, MD,[*] Roland Stroobandt, MD, PhD, FHRS,[*]
Yves Vandekerckhove, MD,[‡] Rene Tavernier, MD, PhD,[‡] Mattias Duytschaever, MD, PhD[*‡]

From the [*]Ghent University Hospital, Heart Center, Ghent, Belgium, [†]Applied Biomedical Systems, Maastricht, The Netherlands, and [‡]Sint-Jan Hospital Bruges, Department of Cardiology, Bruges, Belgium.

BACKGROUND Verification of pulmonary vein isolation (PVI) is challenging because of the coexistence of PV and far-field potentials in bipolar electrograms recorded at the left atrial–pulmonary vein (LA–PV) junction.

OBJECTIVE The purpose of this study was to characterize algorithmically LA–PV potentials before and after PVI and to develop an algorithm to differentiate nonisolated from isolated PVs.

METHODS In 61 patients, we characterized—by type (morphology) and parameters—1440 electrograms recorded during sinus rhythm before and after PVI. Based on vein-dependent prevalence of a given type before and after PVI (first step) and based on vein- and type-dependent cutoff values in parameters specific for recordings before and after PVI (second step), we developed a 2-step algorithm to differentiate nonisolated from isolated PVs. We prospectively validated this algorithm in another dataset of 20 patients.

RESULTS Characteristics before and after PVI were as follows: low voltage (10% ± 7% vs 36% ± 15%), monophasic (13% ± 4% vs 27% ± 9%), biphasic (18% ± 4% vs 21% ± 9%), triphasic (22% ± 5% vs 11% ± 13%), multiphasic (26% ± 7% vs 3% ± 3%), double potentials (11% ± 5% vs 2% ± 1%), peak-to-peak amplitude (0.97 ± 0.21 mV vs 0.35 ± 0.23 mV), maximal slope (0.179 ± 0.033 mV/ms vs 0.071 ± 0.029 mV/ms), minimal slope (0.030 ± 0.003 mV/ms vs 0.024 ± 0.002 mV/ms), and sharpest peak (1.82° ± 0.26° vs 3.45° ± 0.85°, $P < .01$ for all except biphasic). Overall sensitivity and specificity of the 2-step algorithm was 100% and 87%, respectively.

CONCLUSION We algorithmically characterized LA–PV potentials before and after PVI in a large dataset (library of types and parameters). This library enabled us to develop an accurate 2-step algorithm to automatically differentiate nonisolated from isolated PVs. The 2-step algorithm is objective and reliable for assessing PV isolation without the need for pacing maneuvers.

KEYWORDS Ablation; Algorithm; Atrial fibrillation ablation; Electrogram; Pulmonary vein isolation; Pulmonary vein potential

ABBREVIATIONS AF = atrial fibrillation; **CMC** = circular mapping catheter; **CS** = coronary sinus; **EAM** = electroanatomic mapping; **EGM** = electrogram; **FFP** = far-field potential; **LA** = left atrium; **LIPV** = left inferior pulmonary vein; **LSPV** = left superior pulmonary vein; **MOL** = modified overall likelihood; **OL** = overall likelihood; **PV** = pulmonary vein; **PV** = pulmonary vein; **PVI** = pulmonary vein isolation; **PVP** = pulmonary vein potential; **RIPV** = right inferior pulmonary vein; **RSPV** = right superior pulmonary vein

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Introduction

Catheter-based pulmonary vein (PV) ablation is a successful strategy in patients with symptomatic atrial fibrillation (AF).[1] Electrical pulmonary vein isolation (PVI) is an essential end-point for successful outcome.[2,3] Verification of PVI is challenging because bipolar electrograms (EGMs) recorded by circular mapping catheters (CMCs) at the left atrium–pulmonary vein (LA–PV) junction may contain local PV potentials (PVPs) and far-field potentials (FFPs).[3] The aims of this study were (1) to characterize systematically the type and parameters of LA–PV potentials before and after PVI in a large dataset of recordings (library of 1440 EGMs) and (2) to introduce and validate an algorithm to automatically verify PVI.

Methods

Database

Data were collected from 61 patients undergoing electroanatomic mapping (EAM)-guided first circumferential PVI for symptomatic AF (58 ± 9 years, 80% paroxysmal, no structural heart disease). From these patients (244 PVs), we selected only PV recordings in which (1) PV automaticity was observed after ablation (unambiguous proof of isolation)

Address reprint requests and correspondence: Dr. Milad El Haddad, Ghent University Hospital, De Pintelaan 185, 9000 Ghent, Belgium. E-mail address: milad.elhaddad@ugent.be.

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and (2) baseline PV recording was available with CMC at the same position as after PVI. As such, we performed paired analysis in 160 recordings: 16 left superior pulmonary vein (LSPV), 11 left inferior pulmonary vein (LIPV), 37 right superior pulmonary vein (RSPV), and 16 right inferior pulmonary vein (RIPV). The resulting library of 1440 LA–PV electrograms (9 bipoles per PV recording) was used for characterization of LA–PV potentials and development of an algorithm to verify PVI. The study was approved by the local ethical committee.

Ablation procedure and recording catheters

A decapolar catheter was positioned in the coronary sinus (CS). Three-dimensional reconstruction of LA was made by EAM (CARTO, Biosense Webster, Diamond Bar, CA) using an irrigated-tip catheter (NaviStar ThermoCool, Biosense Webster). Ipsilateral PVs were encircled by a circular lesion during sinus rhythm. Except for the anterior ridge of left PVs, lesions were created >10 mm outside the ostia (point-by-point radiofrequency, 20–35 W, 30–60 seconds, max 42°C, 20 mL/min). PVI was assessed using a decapolar (2-mm electrodes, 8-mm spacing) CMC (Lasso, 2515 variable catheter, Biosense Webster). The CMC was positioned at the very ostium of the tubular portion of the vein by experienced electrophysiologists (MD and RT >1500 procedures) and was confirmed by EAM. The end-point was LA–PV entry block, defined as elimination of all PVP or PV automaticity.[4]

Intracardiac EGMs were recorded using the Bard EP system (Boston Scientific, Natick, MA), sampled at 1000 Hz, and filtered at 10–250 Hz. For each selected PV, we extracted 3-second recordings from the surface ECG (lead II), proximal CS bipole, and 9 bipolar CMC-EGMs (1-2, 2-3, …). Each CMC bipole was assigned a hemisphere (anterior or posterior) based on its EAM location. Representative recordings are shown in Figure 1.

Preprocessing of LA–PV electrograms

Preprocessing was performed offline using Matlab (The MathWorks Inc, Natick, MA). First, atrial potentials were detected on the CS electrogram (peak detection algorithm) to determine the atrial activation window of interest (Figure 2, step A). Second, nonatrial potentials were blanked from the LA–PV electrogram of interest (Figure 2, step B). Third, LA–PV potentials in the LA–PV electrogram were detected using a peak detection algorithm (Figure 2, step C). Then, all detected LA–PV potentials (ranging from 2 to 6 beats) were time aligned (using the maximal positive or negative peak) and averaged into 1 LA–PV potential (Figure 2, step D).

Typology of LA–PV potentials

Custom-made Matlab software determined the type of LA–PV potential based on the number of detected peaks (Figure 2, step E). A local maximum was considered a

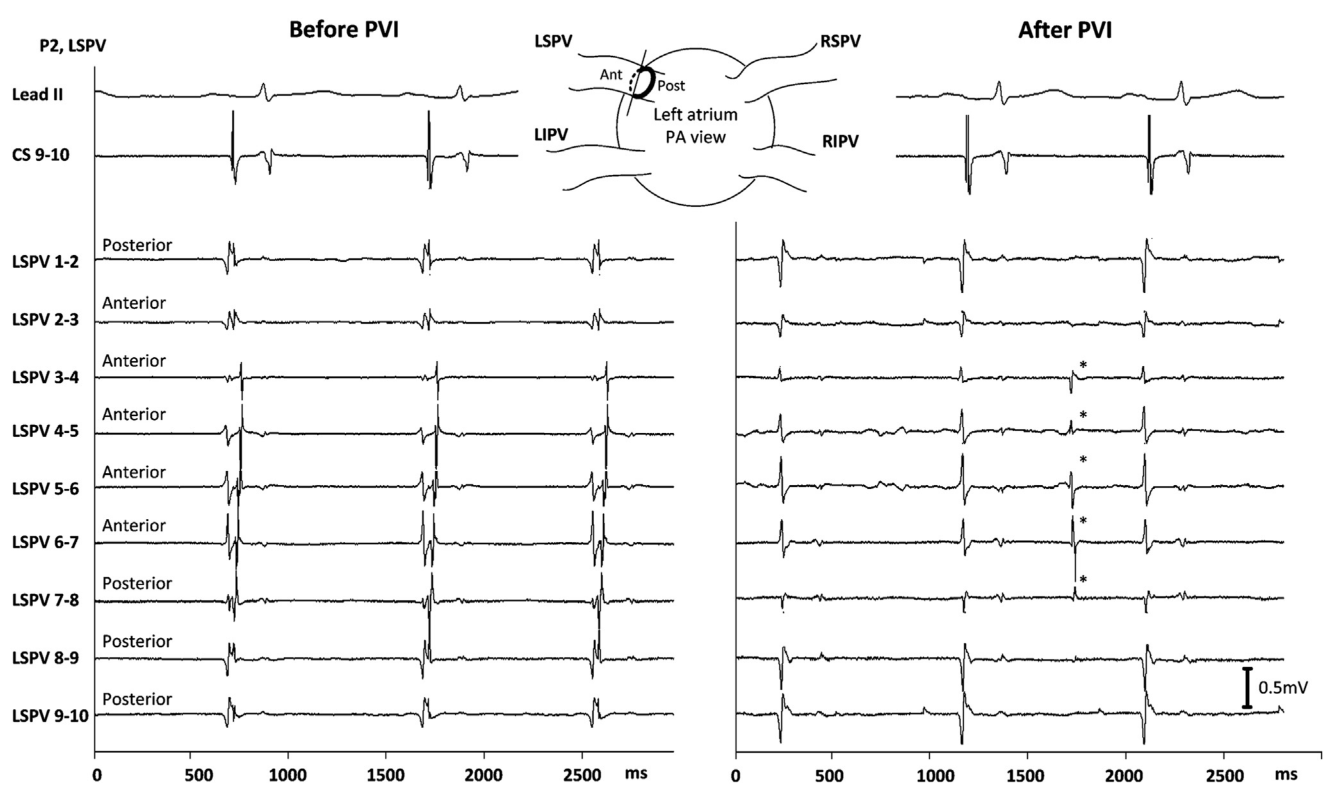

Figure 1 Electrogram tracings from surface ECG lead II, proximal coronary sinus (CS), and circular mapping catheter (CMC) at the left superior pulmonary vein (LSPV) before and after pulmonary vein isolation (PVI). *Asterisk* indicates automaticity. LIPV = left inferior pulmonary vein; RIPV = right inferior pulmonary vein; RSPV = right superior pulmonary vein.

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