Three-Dimensional Impedance Mapping as an Aid to Circumferential Pulmonary Vein Isolation in Paroxysmal Atrial Fibrillation

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During circumferential pulmonary vein isolation, radiofrequency lesions are created in the transition zone between the left atrium and the pulmonary veins, outside the ostia, to avoid stenosis. Three-dimensional impedance maps were constructed for 25 patients with paroxysmal atrial fibrillation. In the first 15 patients, impedance was measured inside the pulmonary veins (165.4 [7.5] Ω), the ostium (141.6 [7.3] Ω), and the left atrium (131.09 [8.3] Ω). An impedance of 136 Ω identified the outer limit of the atrium (area under the receiver operating characteristic curve, 0.85). In the subsequent 10 patients, a single operator who was blinded to the anatomic position of the catheter tip was able to determine, by impedance measurement alone, whether the point targeted for radiofrequency ablation was in the left atrium or the ostium of the pulmonary vein. The positive predictive value for identifying the left atrium was 91% and the negative predictive value was 73%. In patients with paroxysmal atrial fibrillation, threedimensional impedance mapping was helpful in guiding circumferential pulmonary vein isolation.

Key words: Catheter ablation. Three-dimensional mapping. Atrial fibrillation.

Mapas tridimensionales de impedancia para guiar el aislamiento circunferencial de las venas pulmonares en la fibrilación auricular paroxística

En el aislamiento circunferencial de las venas pulmonares, se realizan lesiones de radiofrecuencia en la zona de transición auricular y venosa, fuera de los ostia, para evitar las estenosis. Se construyó un mapa tridimensional de impedancias en 25 pacientes con fibrilación auricular paroxística. En los 15 primeros se midieron las impedancias del interior de las venas (165,4 \pm 7,5 Ω), el ostium $(141,6 \pm 7,3 \Omega)$ y la aurícula izquierda $(131,09 \pm 8,3 \Omega)$. Una impedancia de 136 Ω definía el límite auricular (área bajo la curva ROC = 0,85). En los siguientes 10 pacientes, un operador que desconocía la posición anatómica del catéter clasificó por la impedancia los puntos para aplicar radiofrecuencia como aurícula izquierda u ostium de vena pulmonar, con valor predictivo positivo del 91% y negativo del 73% para identificar aurícula izquierda. En pacientes con fibrilación auricular paroxística, los mapas tridimensionales de impedancia son de ayuda para guiar el aislamiento circunferencial de las venas pulmonares.

Palabras clave: Ablación con catéter. Cartografía tridimensional. Fibrilación auricular.

INTRODUCTION

Circumferential pulmonary vein (PV) isolation has proven to be an effective treatment for atrial fibrillation.¹ Radiofrequency lesions are created in the transition zone between the ostia of the PV (PVO) and the left atrium (LA), avoiding stenosis of

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the PV,² in addition to eliminating rotors, drivers, and lymph plexuses occupying this region.³ It is known that impedances (R_B) of the PV (R_{PV}), their ostia, and the LA (R_{LA}) are different,⁴⁻⁷ and consequently the transition zone could be identified using 3-dimensional impedance mapping to guide ablation safely.

METHODS

The study included 25 patients (15 in the baseline study and 10 in the prospective phase) who underwent ablation for paroxysmal atrial fibrillation (Table 1). Transesophageal echocardiogram and computerized tomography of the chest were performed. The study was done with the patients under sedation with remiferitanil and anticoagulation with sodium

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Patients, n	25
Age, mean (SD), y	50 (9)
Men, n	20
Duration of arrhythmia, mo	64 (52)
Episodes/month/patient	18 (10)
Antiarrhythmic drugs I and III	1.7 (0.5)
Heart disease, n	4
Hypertrophic cardiomyopathy, n	2
Ischemic cardiopathy, n	2
Hypertension, n	8
Left atrium size, mm	40 (3)
Ejection fraction, %	57 (8)

heparin. By means of a transseptal puncture a circular catheter was inserted into the LA to sequentially map each PV (Lasso, Biosense-Webster) with a 3.5 mm irrigated tip ablation catheter (Navi-Star, ThermocoolTM, Biosense-Webster).

Construction of the Impedance Map

The impedance circuit was composed of the radiofrequency generator (Stockert, Biosense-Webster), the ablation catheter and the reference patch (Ref-Star, Biosense-Webster) placed on all the patients between the second and sixth thoracic vertebrae. The R_B was measured after the generator delivered a 50 kHz low amplitude (2 μ A) electric current. Contact between the catheter and the tissue was considered to be optimal if the movement of the catheter and the electric signal were stable. For each point examined, the R_B was measured at least twice before being recorded. To be considered valid it could not vary by more than 2 Ω in the same position.

Three-dimensional impedance mapping of the LA and the PV was carried out with an electroanatomical mapping system (CARTO XP, Biosense-Webster) with color-coding (red, the lowest value; violet, the highest) of the R_B. Each PV and the LA were reconstructed on independent maps. With the ablation catheter, points were acquired from the interior of each PV (1-3 cm) up to the PVO, where points were taken along the entire circumference. The PVO was defined by the simultaneous appearance of an electric signal corresponding to the PV potential together with the LA potential in the distal electrode, and the absence of the PV potential in the proximal electrode, coinciding with the penetration of the catheter into the cardiac silhouette. It was considered to be in the LA when the appearance of the electric signal of the LA in the distal electrode without PV potential coincided with the characteristic movement of the catheter on exiting the vein. In the LA, points were taken on the posterior wall, roof, septum, mitral annulus, and appendage, taking special care and acquiring the greatest number of points possible in the vicinity of the PVO. The map obtained was incorporated into the computerized tomography image (CARTO MERGE Biosense-Webster) (Figure 1).

Prospective Phase. Ablation

In the last 10 patients, an independent operator, blinded to the location of the catheter in the CARTO, classified 36 points per patient (Figure 1) as LA or PVO reading only the R_B value. An R_{LA} + $4\% \Omega$ (see below) was considered to be the impedance limit of the LA. Another operator who did not know the R_B value classified the same point as LA or PVO with the CARTO. In all patients a circumferential ablation of the PV was performed by making an encirclement or circlet of ipsolateral veins (to an atrial electrogram voltage reduction of up to 90% or <0.05 mV) according to the impedance lines of the map (Figure 2), with radiofrequency applications of 35 W and a maximum temperature of 45°C. In the event of "distortion" of the impedance line, the anatomic image was used to select the application. If isolation of the PV was not achieved



Figure 1. A: impedance map integrated into the computerized tomography (CARTO MERGE). B-C: diagram of 36 points acquired around the pulmonary veins (PV). LIPV indicates left inferior PV; LSPV, left superior PV; RIPV, right inferior PV; RSPV: right superior PV



Figure 2. A-D: projections of a 3-dimensional impedance map with a range between 133 Ω , lower limit in the left atrium (LA) (red), and 166 Ω (violet) that is the superior limit obtained 1-3 cm within the pulmonary veins (PV). Impedance gradient from deep PV to LA stands out, as does the LA-PV transition (red-green). E-H: ablation (red dots) following the impedance lines in the PV-LA junction.

with the encirclement, confirmed by the disappearance of all the potentials in each PV with the Lasso catheter, energy was applied in the interior of the circlet until the aim of the ablation was achieved, which was isolation of all the PV. All patients were discharged with antiarrhythmia medication for 3 months and a control cardiac computerized tomography was performed.

The statistical package SPSS14 (Chicago, IL) for Windows was used. The Student *t* test was used to identify significant differences between impedance means. The receiver operating characteristic (ROC) curve was drawn to graphically show the sensitivity and specificity of a particular impedance value that differentiated LA from PVO.

RESULTS

In the first 15 patients an R_B gradient was observed from the interior of the PV (1-3 cm) to the LA: R_{PV} , 165.4 (7.5) Ω ; R_{PV} ostium, 141.6 (7.3) Ω ; R_{LA} , 131.09 (8.3) Ω (Table 2), which was maintained individually in each patient (Figure 3A). The R_{LA} showed no differences in the various zones analyzed (septum, mitral annulus, posterior wall, and roof), but was higher at the base of the left atrial appendage and at its vertex (Table 2). A value of 136 Ω (RL_A + $4\% \Omega$) defined the limits of the LA with 80% sensitivity, 80% specificity, and area under the ROC curve = 0.85 (95% confidence interval, 0.79-0.90) (Figure 3B).

TABLE 2. Impedance Values

Region	Impedance, Ω
Left atrium, meanª	131.1 (8.3)
Left appendage	
Base	135.4 (14.3)
Vertex	149.3 (16.4)
Pulmonary vein ostium, mean	141.6 (7.3)
Left superior	140.8 (7.1)
Left inferior	141.9 (9.1)
Right superior	141.4 (7.2)
Right inferior	142.2 (8.3) ^b
Deep pulmonary vein, mean	165.4 (7.5)

aIncludes all zones of the left atrium.

^bP<.001 with left superior pulmonary vein ostium.

In the final 10 patients an observer, who was only aware of the R_B classified as LA (\leq R_{LA} + 4% Ω) 206 (85%) of 242 CARTO points in the LA, and as PVO (>R_{LA} LA + 4% Ω) 98 (83%) of 118 CARTO points in the PVO (91% positive and 73% negative predictive value for identifying the LA). Using the impedance lines as a guide, all the PV were isolated, and application in the interior of the crown was necessary in up to 10% of the PV. If the R_B rose more than 4% Ω , the radiofrequency application was stopped. The mean radiofrequency time for the left circlet was 22 (9) min and for the right, 19 (6) min. There were no complications. Seventy percent of the patients were free of atrial arrhythmias at 5 (3) months. No PV stenosis was observed on computerized tomography of the chest.



Figure 3. A: impedance gradient between the pulmonary vein ostia (PVO) (by vein) and the left atrium (LA) in the first 15 patients. B: ROC curve of impedance to differentiate between LA and PVO; AUC, area under the curve.

DISCUSSION

A high to low linear impedance gradient exists from the deep PV to the LA, which is homogeneous and constant for each patient. It is possible to reconstruct a 3-dimensional impedance map of the LA and of the PV in which, adjusting the scale by 4% of the impedance above the mean value of the R_{LA} , the transition zone can be defined so that circumferential isolation may be safely performed.

The baseline cardiac impedance value is determined by a multitude of factors, some biological, such as the volume of blood inside a chamber, its radius or the pulmonary resistivity adjacent to a vein.^{4.7} Extrinsic factors must also be kept in mind, such as the size and positioning of the reference patch, the size of the mapping catheter electrode, the pressure exerted on the tissue, the source of energy used and factors related to the patient, such as body surface.⁴⁻⁷ All this means that the R_B varies for each investigator and each center, which is why values should be known by each. What is important is that, although each patient has a different R_B, a linear and constant downward gradient is maintained from the interior of each PV to the LA.

The PV-LA junction is a histologically complex zone with myocardial fibers interwoven in various directions.⁸ Electrical resistivity is determined by the direction of the fibers⁹ and the degree of fibrosis, both of which can explain the differences in R_B obtained in this zone. We prospectively validated that $R_{LA} + 4\% \Omega$ defines a safety zone in the LA to guide circumferential isolation. Unlike the model used by Lang et al,⁷ we consider a percentage and not an absolute increase in R_{LA} to be more exact, as it varies from patient to patient.

Mapping of each PV, instead of the virtual tubes that are generally used, allows delimitation of their shape and observation of the impedance gradient when the catheter is advanced towards the PVO. In this way, small branches of the PV are identified and coded with higher impedance, thereby avoiding the risk of applying radiofrequency in the interior. It is also useful when there exist right accessory branches (2 in our population).

The main limitation of the study is the identification of the PVO in the absence of PV imaging.¹⁰ Imaging techniques, with their limitations, could have helped with a more exact localization of the PVO, but the combination we used of fluoroscopy, electrical signals and catheter movement can be recognized as valid. This study was limited to patients who underwent a single ablation procedure and who had paroxysmal atrial fibrillation. The results should not be translated to patients having already undergone ablation or with chronic atrial fibrillation.

In conclusion, 3-dimensional impedance mapping allows identification of the transition zone between the PVO and the LA, and is helpful for guiding circumferential isolation of the PV.

REFERENCES

 Oral H, Scharf C, Chugh A, Hall B, Cheung P, Good E, et al. Catheter ablation for paroxysmal atrial fibrillation: Segmental pulmonary vein ostial ablation versus left atrial ablation. Circulation. 2003;108:2355-60.

- Saad E, Rossillo A, Saad C, Martin DO, Bhargava M, Erciyes D, et al. Pumonary vein stenosis after radiofrequency ablation of atrial fibrillation. Functional characterization, evolution and influence of the ablation strategy. Circulation. 2003;108: 3102-7.
- 3. Jalife J, Berenfeld O, Mansour M. Mother rotors and fibrillatory conduction: a mechanism of atrial fibrillation. Cardiovasc Res. 2002;54:204-16.
- Cheung P, Hall B, Chough A, Good E, Lemola K, Han J. Detection of inadvertent catheter movement into a pulmonary vein during radiofrequency catheter ablation by real-time impedance monitoring. J Cardiovasc Electrophysiol. 2004;15:674-8.
- Reithmann C, Remp T, Hoffmann E, Matis T, Wakili R, Steimbeck G. Different patterns of the fall of impedance as the result of heating during ostial pulmonary vein ablation: implications for power titration. Pacing Clin Electrophysiol. 2005;28:1282-91.

- Vasegui M, Cesario DA, Valderrábano M, Boyle NG, Ratib O, Finn JP, et al. Impedance monitoring during catheter ablation of atrial fibrillation. Heart Rhythm. 2005;2: 914-20.
- Lang C, Gugliotta F, Santinelli V, Mesas C, Tomita T, Vicedomini G, et al. Endocardial impedance mapping during circumferential pulmonary vein ablation of atrial fibrillation differentiates between atrial and venous tissue. Heart Rhythm. 2006;3:171-8.
- Moubarak JB, Rozwadowski JV, Strzalka CT, Buck WR, Tan WS, Kish GF, et al. Pulmonary vein-left atrial junction: anatomic and histologic study. Pacing Clin Electrophysiol. 2000;23:1836-8.
- 9. Kucera J, Rudy Y Mechanistic insights into very slow conduction in branching cardiac tissue. Circ Res. 2001;89: 799-807.
- Pérez-Castellano N, Villacastín J, Moreno J, Rodríguez M, Moreno M, Conde A, et al. Errors in pulmonary vein identification and ostia location in the absence of pulmonary vein imaging. Heart Rhythm. 2005;2:1082-9.