Original Research

Integration of Intracardiac Echocardiographic Imaging of the Left Atrium with Electroanatomic Mapping Data for Pulmonary Vein Isolation: First-in-Greece Experience with the CartoSound™ System and Brief Literature Review

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Introduction: Intracardiac echocardiography (ICE) offers the ability to image the left atrium in order to reconstruct a three-dimensional model that can be integrated with electroanatomic data to guide pulmonary vein isolation. We report a case series representing the first-in-Greece experience with the CartoSound module.
Methods: Patients with paroxysmal or persistent atrial fibrillation (AF) referred for pulmonary vein isolation were included in this case-series. The SoundStar ICE catheter was used to trace left atrial and pulmonary vein contours from the right atrium, the right ventricular outflow tract and the coronary sinus.
Results: Eight patients (age 66.3 ± 1.6 years) are presented in this case-series report. Six of them (75%) had paroxysmal AF and the rest were in persistent AF for less than one year. The time for ICE imaging and left atrium three-dimensional reconstruction decreased from a median of 20.5 minutes (interquartile range 19.3-23.3) for the chronologically first four cases to a median of 16.5 minutes (interquartile range 14.5-17.0) for the chronologically last four cases ($p=0.02$). The procedure was completed in all cases. No significant periprocedural complications were encountered. Acute success, with restoration of sinus rhythm, was achieved in both patients with persistent AF. Seven of the eight patients (87.5%) were AF-free in 48-hour Holter recordings one week after the procedure.
Conclusion: ICE integration into three-dimensional electroanatomic reconstruction of the left atrium provides reliable guidance for pulmonary vein isolation. It appears that this modality is a sound alternative to magnetic resonance and computed tomography image data registration, although randomized comparisons are lacking.

Atrial fibrillation (AF) is the most common sustained arrhythmia and its prevalence is increasing. It presents several important challenges with regard to the management of the arrhythmia itself and its sequelae.[1,2] Catheter-based ablation treatment of AF through pulmonary vein isolation has emerged over the last few years as a promising therapeutic modality for a substantial number of patients with both paroxysmal and persistent AF, with reported success rates at one year ranging from 56% to 89%.[3,4] However, left atrial ablation for AF treatment is a complex and technically challenging procedure and may entail serious periprocedural and late complications. Image data integration into electroanatomic mapping reconstructions has been applied in order to guide pulmonary vein isolation and to avoid potentially harmful ablation sites. For this purpose, merging cardiac computed tomography and magnetic resonance imaging data with electroanatomic mapping of the left atrium has been common practice over the last few years. However, none of these modalities offers real-time imaging at the time of the procedure and, due to the time lag between the scan and the actual ablation procedure, potential changes in the shape and position of left atrial structures cannot be accounted for.

Intracardiac echocardiography (ICE), on the other hand, offers the ability to image the left atrium in real time during the course of the procedure and to identify all structures which are of import for the ablation.[5] While the simple use of ICE imaging during the ablation, though useful, has little to offer, true integration of ICE imaging data with electroanatomic data, including ablation lines, can be a truly useful tool to guide the ablative intervention. We present the first-in-Greece case series of AF ablation conducted using the CartoSound™ system. In this system, ICE imaging data are used to render a three-dimensional anatomical reconstruction of the left atrium that is incorporated into the CARTO electroanatomic mapping data.

Methods

Patients

Eight consecutive patients with paroxysmal or persistent AF, who were referred for pulmonary vein isolation, were included in this case-series. The subjects had to be less than 75 years of age, in good functional status, with a reasonable expectation to live for at least five years. All patients provided informed consent.

No patient underwent cardiac computed tomography or a magnetic resonance scan before the ablation. All patients received conscious sedation that was maintained throughout the procedure. Patients were followed up with 48-hour ambulatory electrocardiogram recordings one week after the procedure. An absence of AF episodes lasting longer than 30 seconds was defined as short-term success of the treatment.

ICE imaging of the left atrium

Both femoral veins were catheterized and introducer sheaths were placed. An ICE catheter with an incorporated navigation sensor (SoundStar™ catheter, Biosense Webster, Diamond Bar CA, USA) was introduced via a 10-French sheath from the left femoral vein and advanced into the right atrium. It was then manipulated and rotated from several positions in the right atrium, the right ventricular outflow tract and the coronary sinus, in order to obtain multiple sections of the left atrium and the pulmonary veins (Figure 1). Special attention was paid to the correct identification and tracing of the esophagus, which is particularly important to avoid potentially serious complications during the ablation, namely esophageal trauma and/or atrio-esophageal fistula formation (Figure 2). The acquired images were gated to the top of the R wave of the QRS complex recorded on the surface electrocardiogram. By the end of the anatomical mapping procedure a three-dimensional anatomic "shell" of the left atrium had been created (Figure 3).

Ablation procedure

Intravenous unfractionated heparin was administered as a bolus of 80 U/kg before the transseptal puncture and an activated clotting time of 280-320 seconds was maintained with continuous heparin infusion. Transseptal punctures were performed in all patients under constant direct visualization of the *fossa ovalis* with the ICE catheter. A Lasso catheter (Biosense Webster) and an irrigated tip ablation catheter (Navistar Thermocool, Biosense Webster) were introduced into the left atrium. The Lasso catheter was introduced into each of the pulmonary veins and baseline pulmonary vein electrograms were recorded. After the anatomical three-dimensional model of the left atrium had been prepared, ablation was then performed, creating linear radiofrequency lesions around the pulmonary veins approximately 1 cm from the ostia (Figure 4).

The ablation procedure is greatly facilitated by the "show catheter tip" function of the CARTO system, which lets the operator know exactly where in the anatomical three-dimensional model of the left atrium the tip of the ablation catheter is located at any given moment. In addition to the anatomic circumferential ablation around the pulmonary veins, additional lesions were created by the operators, based on the recorded electrograms from the Lasso catheter and the ablation/mapping catheter (ablation of complex fractionated electrograms). The radiofrequency generator (Stockert 70 RF Generator) was set to a temperature limit of 45°C.

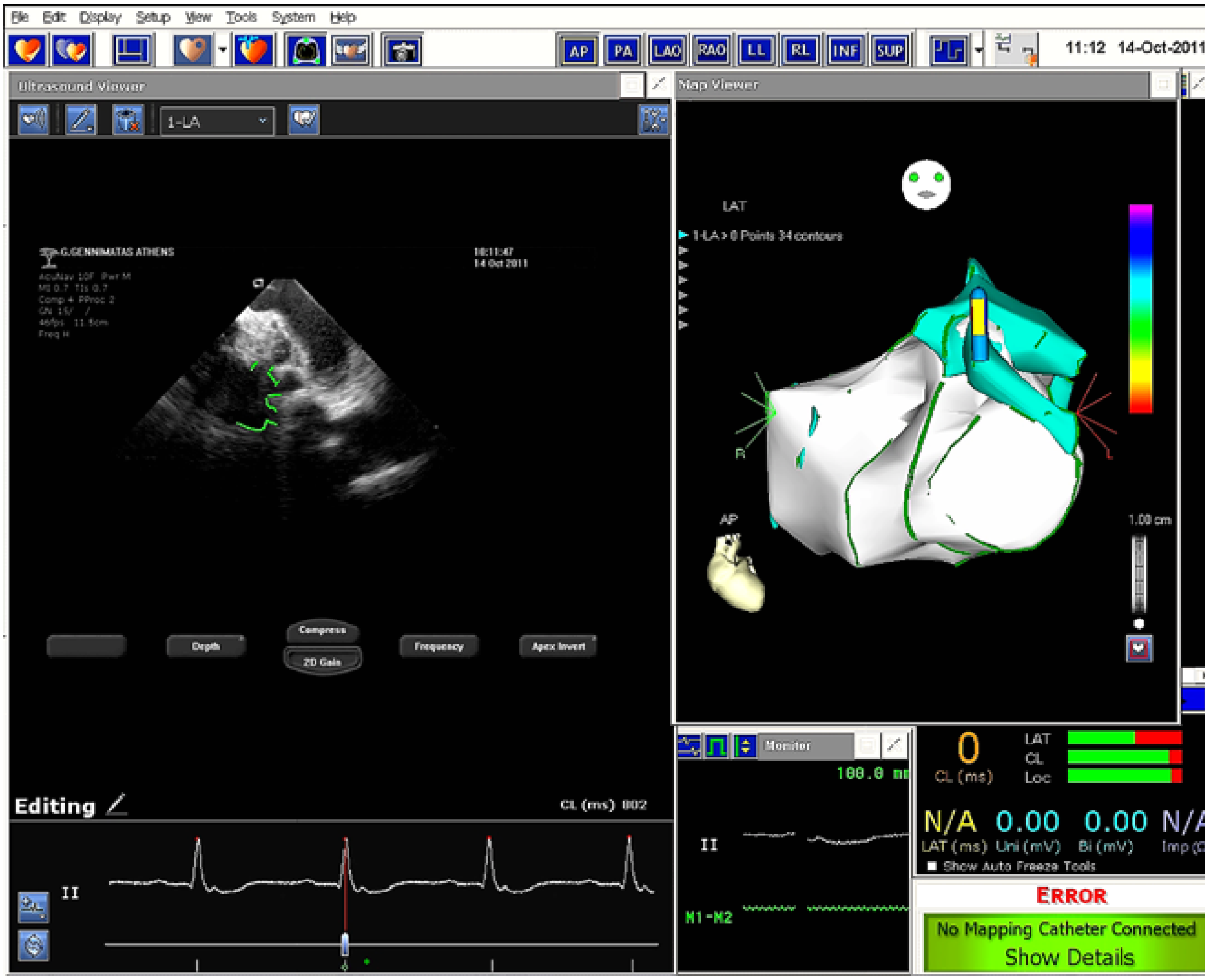

Figure 1. A screenshot from the CARTO XP/CARTO Sound working-station during left atrial mapping with the intracardiac echocardiography (ICE) catheter placed in the right ventricular outflow tract (RVOT). On the left, an ICE section of the left atrium, where the left superior and inferior veins and the left atrial appendage have been traced and added to the rendered three-dimensional "shell" (on the right). The model does not contain any electroanatomic data at this point (the transseptal puncture has not yet been performed and the mapping catheter has not been used, as the "Error" message points out at the right bottom corner of the screen). The position of the ICE catheter (yellow-and-blue-colored) is indicated outside the three-dimensional reconstruction of the left atrium, in the RVOT.

Statistical analysis

Continuous variables were expressed as mean ± standard error of the mean and were compared using a non-parametric test (Mann-Whitney U). Categorical variables were expressed as percentages and counts. The IBM® SPSS® Statistics 19.0 software package was used (SPSS Inc., Chicago IL, USA). Two-sided p-values of less than 0.05 were considered as indicative of statistical significance.

Results

Eight patients (6 males, age 66.3 ± 1.6 years, range 59-72 years), who underwent pulmonary vein isolation with radiofrequency ablation, are presented in this case-series report. Six of them (75%) had paroxysmal AF and two were in persistent AF for less than one year. The mean left atrial diameter was 45.9 ± 1.0 mm and left ventricular ejection fraction was 0.58 ± 0.02.

The time taken to delineate the left atrium and related structures with the ICE catheter decreased significantly from the first to the last patient of the reported series (Figure 5). The time for ICE imaging and left atrium three-dimensional reconstruction decreased from a median of 20.5 minutes (interquartile range 19.3-23.3) for the chronologically first four cases to a median of 16.5 minutes (interquartile

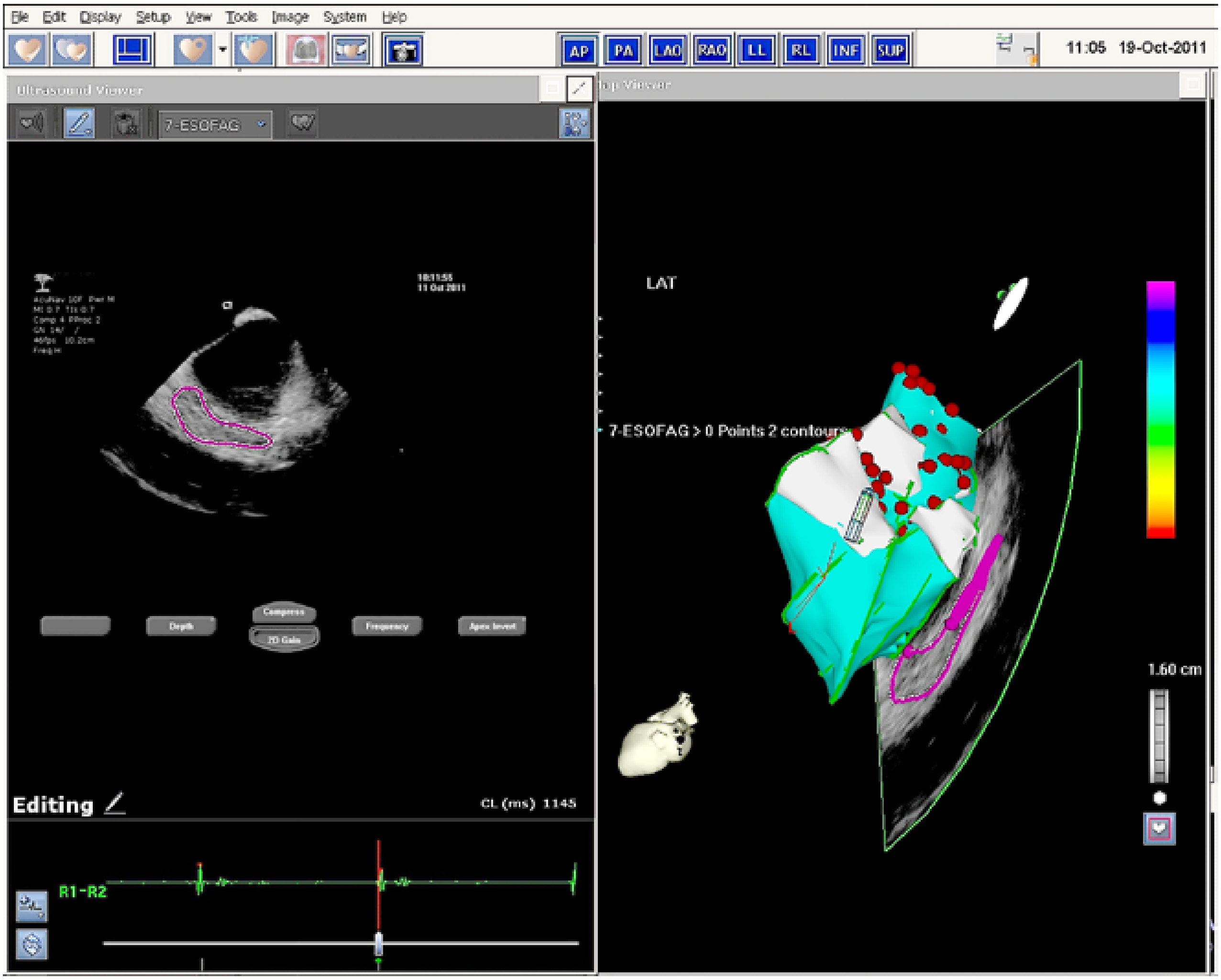

Figure 2. A screenshot from the CARTO XP/CARTO Sound working-station. The esophagus has been traced on multiple two-dimensional planes (an instance of which appears on the left; purple-colored contour) and placed by the software in position relative to the three-dimensional reconstruction of the left atrium (on the right). The operator can thus avoid delivering ablation points in close proximity to the esophagus.

range 14.5-17.0) for the chronologically last four cases (p=0.02). These data clearly indicate a learning curve and a potential for further decrease in the time needed to anatomically map the left atrium with ICE. Moreover, the total procedure duration also declined from 175 minutes (interquartile range 161.3-188.0) in the first four cases to 150 minutes (interquartile range 141.3-158.8) in the last four cases (p=0.03).

The procedure was completed in all cases. No significant periprocedural complications were encountered. Acute success, with restoration of sinus rhythm, was achieved in both patients with persistent AF. Seven of the eight patients (87.5%) were AF-free according to 48-hour Holter recordings one week after the procedure.

Discussion

We present a case series of eight patients representing the first-in-Greece experience with the CARTO Sound system for AF treatment by pulmonary vein isolation. The CARTO system for electroanatomical mapping has developed into a valuable tool for electrophysiologists, guiding therapeutic interventions for almost all kinds of arrhythmias.[6] Ablation of AF through pulmonary vein isolation is a challenging procedure, whose success and associated complication rates are largely dependent on the operator and the equipment. Due to the complex and varying anatomy of the left atrium and the pulmonary veins, general anatomical landmarks and fluoroscopic imag-

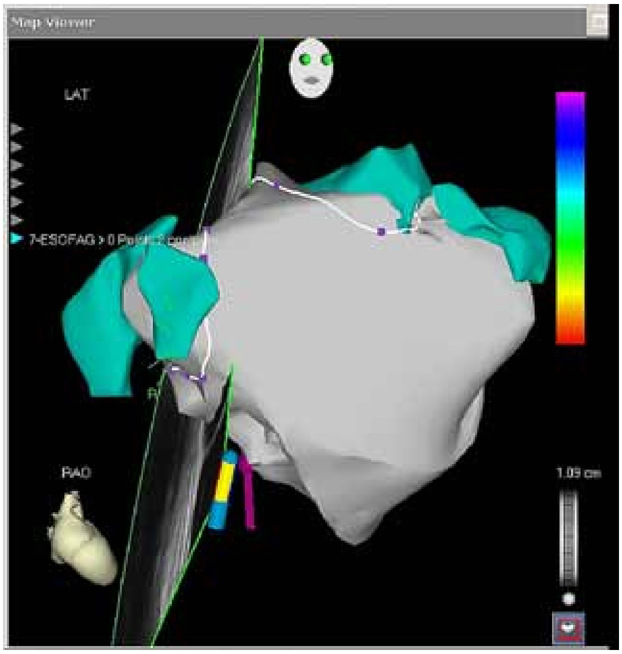

Figure 3. Three-dimensional model of the left atrium (gray color), including the pulmonary veins and the left atrial appendage (green color), reconstructed from multiple two-dimensional sections obtained with intracardiac echocardiography.

ing offer poor guidance for left atrial ablation procedures; image integration, usually with data acquired by computed tomography or magnetic resonance scanning of the left atrium, has thus been employed to accurately guide the safe electrical isolation of the pulmonary vein ostia.[6] However, magnetic resonance has shortcomings associated with availability and cost (particularly true for Greece), while cardiac computed tomography, although more widely available and less costly, entails additional radiation exposure for the patient and also requires contrast medium administration, which can be a problem in patients with kidney disease or hypersensitivity to iodinated contrast agents. In addition, both these modalities come with the disadvantage of the time lag between imaging and the ablative procedure itself, during which changes in anatomical relationships and the shape of the left atrium may intervene—perhaps due to changes in intravascular fluid volume—that may result in the alteration of left atrial volumes and shape. Rhythm transition—from sinus to AF and *vice versa*—in patients with paroxysmal AF from the time of imaging to the time of the ablation procedure may also be a source of error, although this has not been confirmed by relevant studies.[7] Moreover, the procedure of computed tomography/magnetic resonance image data registration is itself subject to inaccuracies,[8] which may be more marked in patients with a larger left atrium.[9]

ICE, on the other hand, provides the electrophysiologist with real-time imaging of cardiac structures. Its use is already widespread, since most laboratories use ICE to safely guide the transseptal punctures and monitor potential complications during the procedure.[10] Integration of ICE imaging into a three-dimensional reconstruction of the left atrium and relevant structures, along with electroanatomic data obtained with the mapping/ablation catheter, is a key upgrade to the usefulness of ICE for AF ablation. Endocardial contours of the left atrium and the pulmonary veins can be obtained before transseptal puncture, by maneuvering the SoundStar catheter (Biosense Webster) in the right atrium, the right ventricular outflow tract and the coronary sinus, if necessary. Real-time imaging ensures correct assessment of the positions of relevant structures, including the esophagus, which can be accurately outlined and integrated into the model of the left atrium, thus avoiding inadvertent heat trauma during the ablation.

Since the first reports of its use in humans,[11,12] the CartoSound system has been employed for guiding ablation procedures, including, but not limited to AF.[13-15] In a recent report,[16] CartoSound-guided pulmonary vein isolation was compared to preprocedural magnetic resonance imaging and the combination of the two (magnetic resonance imaging and ICE). Total procedural time was similar between the groups, but magnetic resonance imaging integration required more fluoroscopy time (in fact double the time needed for ICE image integration) and a longer time spent in the left atrium. Addition of magnetic resonance imaging to ICE integration showed a tendency for a higher fluoroscopy time in comparison to ICE integration alone. Importantly, there were no significant differences in AF recurrences among the groups at 9.1 ± 2.2 months. The authors concluded that ICE image integration significantly reduces fluoroscopy time and the time spent in the left atrium (a parameter linked to the procedure-associated risk of cerebrovascular complications) in comparison to magnetic resonance imaging integration alone. Addition of magnetic resonance imaging to ICE integration does not reduce total procedural time and seems to lead to longer fluoroscopy time in comparison to ICE integration alone.

In conclusion, ICE imaging integration into the three-dimensional electroanatomic reconstruction of the left atrium provides reliable guidance for circum-

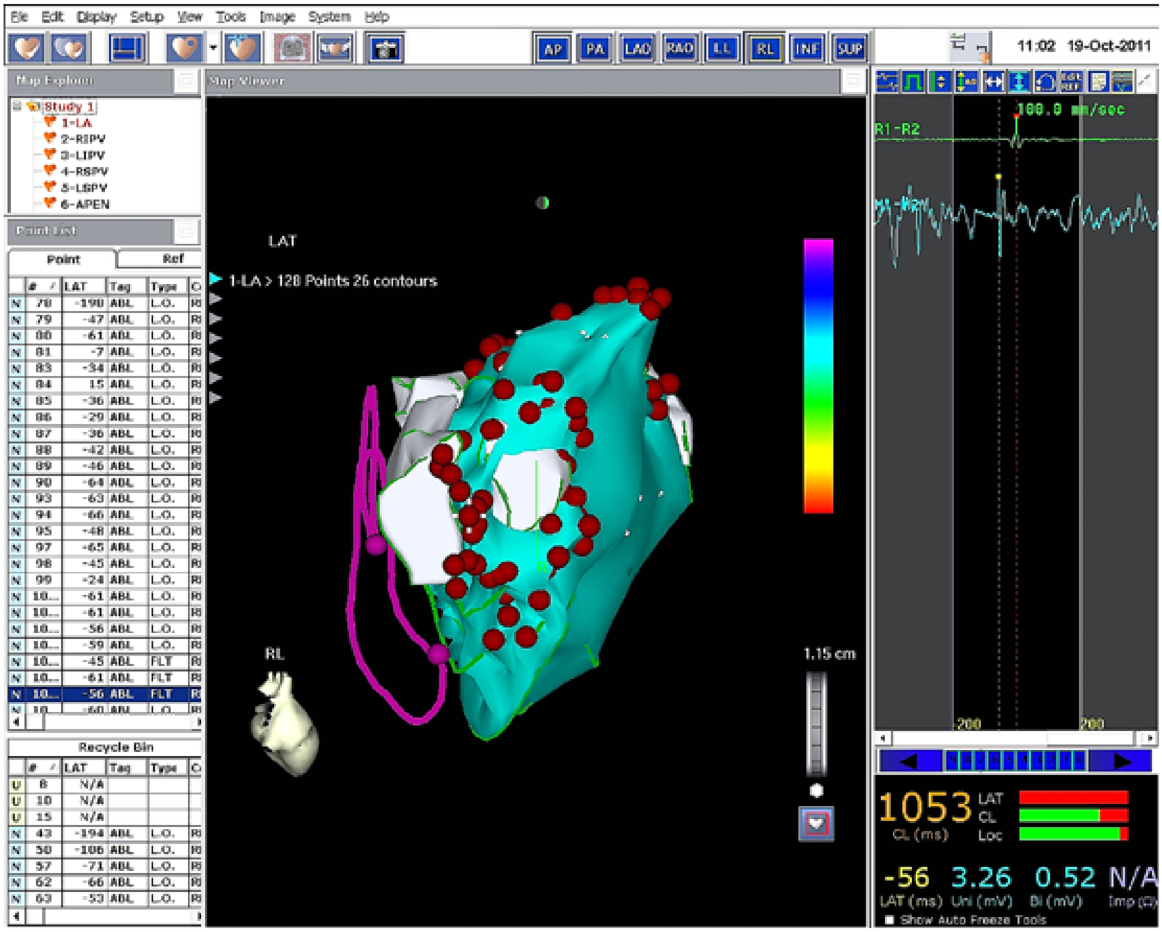

Figure 4. Three-dimensional reconstruction of the left atrium and the pulmonary veins, with ablation points (maroon dots) demarcated around the pulmonary vein ostia (the ablation lines are still incomplete).

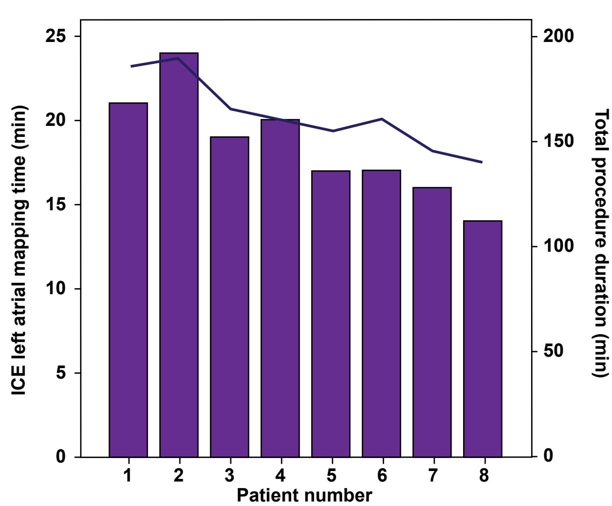

Figure 5. Total procedure duration (thick blue line) and time spent obtaining contours of the left atrium and associated structures with intracardiac echocardiography (bars). The patients are arranged in chronological order, indicating a significant decline in the duration of ICE image acquisition (p=0.02) and total procedure duration (p=0.03).

ferential isolation of the pulmonary veins. ICE is radiation-free, does not require contrast infusion, and is the only modality capable of offering real-time imaging throughout the ablation intervention. In short, it appears to be a safe and effective alternative to magnetic resonance and computed tomography image data registration, although randomized comparisons are lacking. It is conceivable that this modality will see more widespread use in the near future, as the number of AF ablation treatments increases.

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