Blinded correlation study of three-dimensional electro-anatomical image integration and phased array intra-cardiac echocardiography for left atrial mapping

Marcos Daccarett¹, Nathan M. Segerson¹, Jens Günther², Georg Nölker², Klaus Gutleben², Johannes Brachmann², and Nassir F. Marrouche¹*

¹Division of Cardiac Electrophysiology, University of Utah Health Science Center, 4A100, 30 North 1900 East, Salt Lake City, UT 84132, USA; and ²Department of Cardiology, Medizinische Klinik, Klinikum Coburg, Germany

Received 10 June 2007; accepted after revision 11 August 2007; online publish-ahead-of-print 6 September 2007

Aims The purpose of this study was to compare, in a prospective and operator-blinded fashion, the mapping accuracy of the three-dimensional (3D) electro-anatomical image integration and phased array intracardiac echocardiography (ICE) as a real-time imaging modality.

Methods and results Prospectively, 18 patients undergoing pulmonary vein antrum isolation (PVAI) were included. Patients underwent a cardiac computerized tomography scan to define PV and left atrial (LA) anatomy. Image segmentation and integration was performed by CARTOMERGE, followed by 3D volume rendering and image integration. Error profiles between ICE-guided to CARTO and CARTO-guided to ICE were performed in an operator-blinded fashion over PV predetermined points. All patients underwent successful PVAI. The mean age was 55 ± 10 years, with a mean LA size of 4.5 ± 0.3 cm.

CARTOMERGE-guided catheter positioning was subject to spatial errors on the order of 0.5–1.0 cm relative to ICE imaging, with greatest magnitude near the LA appendage (LAA) and least near the RIPV. The magnitude of spatial error between these two methods is demonstrable regardless of the choice of reference.

Conclusion During electro-anatomical mapping of the LA, CARTO-guided navigation is associated with considerable spatial error relative to anatomic features as identified by ICE. Adjunctive real-time imaging is needed to ensure accurate delivery of radiofrequency lesions.

KEYWORDS CARTO; Intracardiac echocardiogram; Ablation; Blinded accuracy

Introduction Radiofrequency catheter ablation has emerged as an important treatment modality in the contemporary management of atrial fibrillation. Various aspects of the ablation technique and its many supportive technologies continue to evolve rapidly. This study focuses on two imaging strategies that exist to help define the left atrial (LA) anatomy and to help in navigating the ablation catheter tip.

First, electro-anatomical mapping is a strategy that generates a virtual three-dimensional (3D) model of the left atrium by tracking the catheter tip position during a survey of endocardial points. This model can then be used during the ablation as an anatomical reference and can help guide catheter manipulation near pulmonary vein (PV) ostia and other complex structures.

In its most contemporary form, the virtual left atrium generated by electro-anatomical mapping can be refined by performing a computer-based 3D image integration with data from computed tomography or magnetic resonance imaging of the left atrium. It is likely that this additional image processing enhances the anatomical accuracy of the resulting model. However, the overall accuracy of 3D image integration remains controversial.¹,²

Intracardiac echocardiography (ICE) is a different strategy that provides the operator a real-time sonographic image representation of LA structures. This modality theoretically provides much improved temporal resolution and, at least in two dimensions, improved spatial resolution as well. However, many sources of potential artifact exist, and extrapolation of images to 3D rely on operator conceptualization.³–⁵ The purpose of this study was to compare, in a prospective and operator-blinded fashion, the mapping accuracy of the 3D electro-anatomical image integration and phased array ICE as a real-time imaging modality.

* Corresponding author. Tel: +1 801 587 4869; fax: +1 801 581 7735. E-mail address: nassir.marrouche@hsc.utah.edu

© The European Society of Cardiology 2007. All rights reserved. For permissions, please e-mail: journals.permissions@oxfordjournals.org
Methods

Prospectively, 18 consecutive patients undergoing PV antrum isolation (PVAI) for atrial fibrillation at the University of Utah (Salt Lake City, UT, USA) and Medizinische Klinik (Coburg, Germany) were included after obtaining written consent. The study was approved by the institutional review boards of both institutions. Both centres followed the same pre-ablation protocol and ablation method.

All patients underwent a cardiac, 64 slice computerized tomography (CT) scan to define PV and LA anatomy 48 h prior to the procedure with a Siemens Sensation-64 scanner (Siemens, Forchheim, Germany) according to a previously described imaging protocol (120 mL non-ionic contrast, collimation 64 × 0.55 mm, and retrospective ECG gating). Image segmentation and integration of the previously obtained CT images and the electro-anatomical map was performed by commercially available software (CARTOMERGE, CARTO XpTM, Biosense Webster, Diamond Bar, CA, USA). The contrast-filled LA and PVs were selected from the raw data set and segmented by intensity threshold determining endocardium and blood pool. The selected structures were then compiled and processed by a 3D volume rendering. This shell geometry was then exported for image integration.

After two trans-septal sheaths were placed in the LA using standard methods, a single operator using fluoroscopic and ICE guidance positioned the lasso catheter at the PV ostia. The posterior aspects of all PVs were then used to initiate landmark registration. Additional surface registration was then performed with fluoroscopic guidance using at least 30 dispersed endocardial positions (Figure 1). A 3.5 mm deflectable tip-mapping catheter (Navistar, Biosense Webster Inc.) was then advanced into the LA.

We then sought to bidirectionally compare errors between two navigation methods. Catheter navigation was randomly assigned to one of two different methods:

(i) Navigation Protocol 1: fluoroscopy and ICE-guidance with the operator blinded to the CARTOMERGE images;
(ii) Navigation Protocol 2: fluoroscopy and CARTOMERGE-guidance (before and after surface registration) with the operator blinded to ICE images.

The operator was asked to position the mapping catheter at five pre-defined LA sites: (i) mid-posterior aspect of the right superior PV (RSPV) ostium, (ii) mid-posterior aspect of the right inferior PV (RIPV) ostium, (iii) mid-posterior aspect of the left superior PV (LSPV) ostium, (iv) mid-posterior aspect of the left inferior PV (LIPV) ostium, and (v) mid-carina between the LA appendage (LAA) and the left superior PV. The mid-posterior aspect of the veins was defined utilizing fluoroscopy and the guidance method established in each of the protocols, determined as the most posterior portion of an equidistant point between the superior and inferior limits of each PV ostium and their junction with the antrum of the LA.

In Navigation Protocol 1, a single adjudicating investigator placed virtual target annotations on the CARTOMERGE geometry, and ascertained the distance between the CARTOMERGE-indicated catheter positions and these targets. In Navigation Protocol 2, the adjudicator recorded ICE images that visualized both catheter tip and target for each of the prescribed anatomical targets, and error distances were measured offline.

After this protocol was completed, all patients underwent successful PVAI as scheduled without procedural complications. Statistical analysis was performed with SAS software (version 9.2, SAS Institute, Inc., Cary, NC, USA). A paired Student’s t-test was used to compare population means. Generalized linear models were applied to compare significance of the error estimates for the different methods and locations. Interclass correlations were

![Figure 1](https://academic.oup.com/europace/article-abstract/9/10/923/498191/924)

Figure 1 3D electro-anatomical image integration mapping system (CARTOMERGE) with pre-determined landmark points. Image integration is shown using a CT reconstruction of the LA.

![Figure 2](https://academic.oup.com/europace/article-abstract/9/10/923/498191/924)

Figure 2 (A) Measurement of variation (error) between the CARTOMERGE to ICE on the left-sided PVs. The blue point depicts the target point on the virtual geometry and the pink point indicates the catheter as positioned using ICE. Delta (Δ) determines the 3D distance between points. The yellow point indicates the catheter position relative to the virtual geometry before surface registration (landmark registration only). (B) ICE image of the catheter position with the operator targeting the mid-septal aspect of the right inferior PV. The blue point depicts the target position on virtual geometry.
calculated after applying a Fisher’s z-transformation. The magnitude and characteristics of the error distribution for the RSPV, RIPV, LSPV, LIPV, and LAA locations of CARTO to ICE positions were collected (Figure 2). Statistical significance was determined by \( P < 0.05 \).

**Table 1** Mean ± SD of the different error measurements by ICE and CARTO, before and after surface registration (SR)

<table>
<thead>
<tr>
<th>Location</th>
<th>ICE to CARTO</th>
<th>CARTO to ICE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Error (cm)</td>
<td>Error post-SR (cm)</td>
<td>P-value</td>
</tr>
<tr>
<td>RSPV</td>
<td>0.62 ± 0.20</td>
<td>0.55 ± 0.14</td>
</tr>
<tr>
<td>RIPV</td>
<td>0.51 ± 0.16</td>
<td>0.50 ± 0.11</td>
</tr>
<tr>
<td>LSPV</td>
<td>0.75 ± 0.11</td>
<td>0.60 ± 0.07</td>
</tr>
<tr>
<td>LIPV</td>
<td>0.60 ± 0.12</td>
<td>0.45 ± 0.10</td>
</tr>
<tr>
<td>LAA</td>
<td>0.98 ± 0.20</td>
<td>0.88 ± 0.14</td>
</tr>
</tbody>
</table>

Paired Student’s t-test P-values are described.

**Table 2** Mean ± SD of the different error measurements between ICE and CARTO after surface registration (SR)

<table>
<thead>
<tr>
<th>Location</th>
<th>ICE to CARTO</th>
<th>CARTO to ICE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Error post-SR (cm)</td>
<td>Error post-SR (cm)</td>
<td>P-value</td>
</tr>
<tr>
<td>RSPV</td>
<td>0.55 ± 0.14</td>
<td>0.54 ± 0.13</td>
</tr>
<tr>
<td>RIPV</td>
<td>0.50 ± 0.11</td>
<td>0.49 ± 0.13</td>
</tr>
<tr>
<td>LSPV</td>
<td>0.60 ± 0.07</td>
<td>0.52 ± 0.08</td>
</tr>
<tr>
<td>LIPV</td>
<td>0.45 ± 0.10</td>
<td>0.52 ± 0.10</td>
</tr>
<tr>
<td>LAA</td>
<td>0.88 ± 0.14</td>
<td>0.88 ± 0.20</td>
</tr>
</tbody>
</table>

Paired Student’s t-test P-values are described.

**Figure 3** Correlation between spatial errors using Navigation 1 and those determined using Navigation 2 (P denotes the probability of slope difference from 0).

**Discussion**

Our principle findings are that (i) despite careful attempts to optimize registration, CARTOMERGE-guided catheter positioning is subject to spatial errors on the order of 0.5–1.0 cm relative to ICE imaging, (ii) spatial errors are reduced by using surface registration, (iii) errors are greatest near the LAA and least near the RIPV, and (iv) the magnitude of spatial error between these two methods is demonstrable regardless of the choice of reference.

The reported spatial error profile is of considerable clinical significance, given that with this error profile, the anatomical distribution of ablation lesions would likely be inadequate to provide a positive clinical result.\(^6\,^7\) This study corroborates the conclusions of Zhong et al.\(^1\) and others, which called into question the suitability of electro-anatomic mapping systems to be used as the sole imaging modality for LA procedures.\(^9\,^{10}\)

These findings do not rebut the potential advantages of a 3D imaging modality. Certainly the spatial resolution and accuracy of both fluoroscopy and ICE are superior to electro-anatomic mapping within a given imaging plane. However, in order to target specific endocardial locations with 2D imaging, the operator must accurately conceptualize the orientation of this imaging plane relative to the complex 3D anatomy of the left atrium. Therefore, just as real-time 2D imaging is an important adjunctive modality to avoid potentially large spatial registration errors inherent to current electro-anatomic mapping technology, virtual navigation remains a key tool for aiding the operator in conceptualizing chamber structures. Furthermore, it should be emphasized that this study does not challenge the accuracy...
of CARTOMERGE or ICE with regard to relative catheter positioning. With adjunctive real-time imaging to corroborate anatomical positioning, electro-anatomic mapping remains a potentially powerful tool for fine catheter manipulation and for recording lesion sets.

Limitations

Our findings are based on a single-operator experience, which eliminates inter-observer bias, but certainly decreases the external validity. This limits the applicability of our error profiles for the different locations during LA mapping for atrial fibrillation ablation.

Conclusions

During electro-anatomical mapping of the left atrium, CARTO-guided navigation is associated with considerable spatial error relative to anatomic features as identified by ICE.9,10 This report underscores the need for adjunctive real-time imaging to ensure accurate delivery of radiofrequency lesions during LA ablation procedures.

Conflict of interest: None declared.

References