Registration of Three-Dimensional Left Atrial Computed Tomographic Images With Projection Images Obtained Using Fluoroscopy

Jasbir Sra, MD; David Krum, MS; Angela Malloy, BS; Melissa Vass, BS; Barry Belanger, PhD; Elisabeth Soubelet, PhD; Regis Vaillant, PhD; Masood Akhtar, MD

Background—Anatomic structures such as the left atrium and the pulmonary veins (PVs) are not delineated by fluoroscopy because there is no contrast differentiation between them and the surrounding anatomy. Representation of an anatomic structure via a 3D model obtained from computed tomography (CT) imaging and subsequent projection of these images over the fluoroscopy system may help in navigation of the mapping and ablation catheter to the appropriate sites during electrophysiology procedures.

Methods and Results—In this feasibility study, in vitro experiments were performed with a plastic heart model (phantom) with 2 catheters or radiopaque platinum beads placed in the phantom at the time of CT imaging and fluoroscopy. Subsequently, 20 consecutive patients underwent contrast-enhanced, ECG-gated CT scanning. Left atrial volumes were generated from the reconstructed data at ~75% of the R-R interval during the cardiac cycle. Similarly, the superior vena cava and the coronary sinus were also reconstructed from these images. During the electrophysiology procedure, digital records (cine sequences) were obtained. Using predetermined algorithms, both the phantom model and the patients’ 3D left atrial models derived from the CT were registered with projection images of fluoroscopy. Registration was performed with a transformation that linked the superior vena cava and the coronary sinus from the CT model with a catheter placed inside the coronary sinus via the superior vena cava. Registration was successfully accomplished with the plastic phantom and in all 20 patients. Registration accuracy was assessed in the phantom by assessing the overlapping beads seen both in the CT and the fluoroscopy images. The mean registration error was 1.4 mm (range 0.9 to 2.3 mm). Accuracy of the registered images was assessed in patients with recordings from a basket catheter placed sequentially in the superior PVs and by injecting contrast into the PVs to assess overlapping of contrast-filled PVs with the corresponding vessels on the registered images. The images could be calibrated quite accurately. Any rotational error, which was usually minor, could be corrected by rotating the images as needed.

Conclusions—Registration of 3D models of the left atrium and PVs with fluoroscopic images of the same is feasible and could enable appropriate navigation and localization of the mapping and ablation catheter during procedures such as atrial fibrillation ablation. (Circulation. 2005;112:3763-3768.)

Key Words: ablation □ atrium □ imaging □ registration □ image-guided therapy

Catheter ablation is an evolving procedure for the treatment of atrial fibrillation (AF).1–4 Because it provides real-time images, x-ray fluoroscopy is commonly used to track catheters through the complex 3D geometry of the heart during mapping and ablation of arrhythmias. The left atrium and the pulmonary veins (PVs), however, cannot be seen with fluoroscopy because they do not present contrast against the surrounding structure. ECG-gated cardiac imaging, using computed tomography (CT) and segmentation, allows 3D rendering of the left atrium free of motion.5,6 The combination of the 2 modalities could thus differentiate the left atrium and the PVs from the surrounding structures and help navigate the mapping and ablation catheter to the appropriate locations. In addition, availability of real-time fluoroscopy allows for rapid correlation of anatomic structures and catheter location. In this report, we describe the feasibility of registering the CT-derived 3D left atrial model with projection images of fluoroscopy.

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Methods

Study Design
The study was performed in 2 phases. In phase 1, in vitro experiments were performed with a plastic model (phantom) of the left atrium. The second phase involved determining whether it was...
Registration: Technical Considerations

Registration can be used to synchronize or align images obtained from different modalities. One way to accomplish this is to use a geometric transformation that aligns points (also called fiducial points) or anatomic features.7–11 A transformation or mathematical process can be defined to orient the coordinate systems from the 2 modalities in the spatial domain. The number of parameters needed to describe a transformation (registrations) is referred to as the degrees of freedom. In the case of a phantom, there will be no change to the anatomic reference system, the patient table. This is coherent with the CT scanning system used for left atrial imaging. During CT imaging and fluoroscopy, the phantom or patient was placed in the same position so that any relative rotation between the 2 systems would be negligible.

Phantom Studies

Three different CT images of the phantom were obtained for registration for each of the phantom studies with catheters or platinum beads. The plastic model of the left atrium used was Angiogram Sam (Medical Plastics Laboratory, Inc; Figure 1A). In the first series of experiments using the phantom, a 10-pole 7F lasso catheter (Biosense Webster) and a 20-pole 7F coronary sinus catheter (St. Jude Medical) were taped in place at the time of CT imaging and fluoroscopy for subsequent registration. Fluoroscopic images were obtained with the phantom placed in the same position as during CT imaging, and registration was performed between the 3D model and the fluoroscopic image. Image scaling or calibration was performed automatically by the registration application. Registration accuracy was determined by assessment of the overlapping of the catheter in the CT model with the fluoroscopic images on the registered model (Figure 1). Any real or apparent misregistration was evaluated by rotation of the phantom images as needed (Figure 2). In a second set of experiments, platinum bead electrodes (1 mm in diameter) were used in place of catheters to assess the accuracy of phantom registration. The beads were attached to the model in various locations, some in close proximity to the coronary sinus. These beads were used to assess registration accuracy (Figure 3). Digital calipers were used for this purpose to measure the distance from the center point of the beads.

Patient Studies

Imaging and Segmentation

All patients were scanned with contrast-enhanced ECG-gated CT scan (Lightspeed Ultra, GE Healthcare). The process of imaging and segmentation of the left atrium has been described previously.6 Patients were kept stationary and level during CT imaging to avoid introduction of any rotational errors. To eliminate misregistration due to cardiac motion, retrospective ECG-gated reconstruction of the axial slices was performed at the point in the cardiac cycle that yielded the best image quality. A multiphase snapshot of the data segment was taken during diastole, with approximately 70% to 80% phase location, because the best image quality was seen during diastole. During AF, because of the short R-R interval, the optimum phase location chosen was 45%. The native slice acquisition thickness was 1.25 mm. Left atrial, superior vena cava, and coronary sinus 3D models were segmented for subsequent analysis and registration. Postprocessing software allowed these data segments to be seen separately or together.

Registration

Before registration, a 6F decapolar catheter (St. Jude Medical) was placed in the coronary sinus. A transformation process that linked the catheter imaged on the fluoroscopy system to the superior vena cava and coronary sinus segmented from the CT images was used to register the 3D CT model with the fluoroscopic images. Because the present study by aligning the superior vena cava and the coronary sinus with a catheter placed in the coronary sinus. As in the left atrial model, the superior vena cava and the coronary sinus were segmented with CardEP software (GE Healthcare). The coronary sinus catheter was also used to calibrate the 3D CT image with the registered image. For the purpose of this study, a transformation was identified that linked the segmented superior vena cava and coronary sinus derived from the CT image, the discernible features of the coronary sinus catheter location in the superior vena cava and the coronary sinus, and the relationship of these features to the left atrium.

The image-formation model of a fluoroscopy system is a conic projection. The location of the center of the projection and the position of the imaging plane, in principle, are well described with respect to the anatomic reference system, the patient table. This is coherent with the CT scanning system used for left atrial imaging. During CT imaging and fluoroscopy, the phantom or patient was placed in the same position so that any relative rotation between the 2 systems would be negligible.

Patient Population

Twenty consecutive patients (13 males and 7 females with a mean age of 62 ± 12 years) with paroxysmal AF who were undergoing radiofrequency catheter ablation were included in the study. Seventeen patients were in sinus rhythm during CT imaging and registration. Clinical characteristics of these patients are depicted in the Table.

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LA indicates left atrium; LVEF, left ventricular ejection fraction; and CT, computed tomography.

feasible to register left atrial 3D models obtained by CT with fluoroscopic projection images of patients undergoing AF ablation. All patients gave informed consent. No ablation was performed with the registered data during this study.
anatomic spatial relationship between the superior vena cava and the left atrium was well established within the CT image, registration of the superior vena cava–coronary sinus effectively registered the left atrium. Using coronary sinus catheter motion on fluoroscopy, attempts were made to capture images from the fluoroscopic sequence for registration during diastole, ie, when the catheter was maximally displaced. An 8F multielectrode basket catheter with 64 unipolar electrodes (Boston Scientific) and an 8F transseptal sheath were placed in 1 of the superior PVs via a transseptal approach. Registration accuracy was validated with intracardiac recordings from the multielectrode basket catheter and the coronary sinus and PV angiography (Figure 4). During mapping of the left PVs, left atrial pacing from the distal electrodes of the coronary sinus catheter was performed to identify the site of the electrical ostium. In addition, during each experiment, the multielectrode basket was initially placed far into the PV and withdrawn gradually, so that the proximal electrodes had double potentials. Contrast was then injected into the vein, as shown in Figure 4, to further confirm the location of the multielectrode basket. Contrast was injected into the PVs so that 2 more images were obtained in the 30° right anterior oblique and the left anterior oblique projections. After this, the multielectrode basket catheter and sheaths were placed in the other superior PV, and the process of contrast injection and imaging was repeated. Rotational errors, identified during injection of the contrast into the PVs and coronary sinus, were corrected with the registration software, which allowed for movement of the image in 2 planes to reconfirm whether the coronary sinus and the contrast-filled PV were aligned in both imaging modalities.

An automatic algorithm was used for scaling, both for the phantom and patient studies, which compared the actual and apparent location of the catheter during fluoroscopy in reference to the patient’s table. With knowledge of the actual and apparent dimensions and the elevation of the catheter in the 3D model, the actual size of the left atrium in the 3D registered image and fluoroscopy images could be calibrated.

**Statistical Analysis**

Results are expressed as mean±1 SD for continuous data and as percentages for dichotomous data.

**Results**

**Imaging and Registration of the Phantom Model**

It was possible to image the phantom and register the 3D model with fluoroscopy. Overall, the registration was quite
accurate (Figures 1 and 3). Any minor rotational error was corrected by adjustment of the orientation of the registered image as needed. Any apparent misregistration due to catheter movement was identified as well (Figure 2). Figure 2 depicts CT and fluoroscopic images of the phantom during the third imaging and registration run. The red arrow marks the opening of the catheter and shows that the orientation of the catheter is not correct. A blue line across the area of the superior vena cava, however, shows that calibration was correct in both images. Catheter orientation was corrected by rotating the CT model 7° in a right anterior oblique orientation, as shown in Figure 2C. However, as shown by the yellow arrows, the angle of orientation in Figure 2C is not the same as the angle of orientation in Figures 2A and 2B. This suggests a movement in catheter location between the time of CT imaging and fluoroscopy rather than misregistration. Registration accuracy, as determined by the overlapping of the beads on the registered CT-fluoro model, was 1.43 ± 0.53 mm (range 0.9 to 2.3 mm; Figure 3).

Left Atrial Imaging and Registration in Patients

CT Imaging
Imaging and segmentation reconstruction of the left atrium, superior vena cava, and coronary sinus were performed successfully in all 20 patients. Seventeen patients were in sinus rhythm, and 3 were in AF at the time of imaging. As per our AF ablation protocol, patients who were in AF were converted to sinus rhythm before registration and ablation. A total of 79 PVs (range 3 to 5) were identified. In 2 patients, there was a common ostium of the left PVs, whereas in 1 patient, there was an additional right middle PV. In addition, the esophagus was segmented, and its anatomic relationship to the posterior left atrium was identified in all patients (Figure 5).

Registration
Registration of the left atrium and PVs was accomplished in all patients with the coronary sinus catheter positioned via the superior vena cava. All patients were in sinus rhythm at the time of registration. Manual alignment or adjustment of the automated registration was needed in 51% of the image sequences in 9 patients. After the fluoroscopic images had been imported into the registration platform, the mean time required to reach final registration was 5.1 ± 1.7 seconds (range 3 to 10 seconds). Registration accuracy was confirmed fluoroscopically, electrocardiographically, and angiographically. Intracardiac recordings showing double potentials on the most proximal basket electrodes were used to assess the location of the basket in the PV (Figure 4). Contrast injected into the coronary sinus and PVs, along with the multielectrode basket catheters, also helped validate the registration process by allowing visualization of the superimposition of contrast-filled vessels in the registered models. Accurate superimposition was seen in all PVs.

Discussion
Accurate 3D imaging and the combination of this information with another modality may aid in diagnosis and appropriate therapy delivery.6,12 Radiological scans such as the CT can yield an explicit geometric description of anatomic structures such as the 3D left atrial model.5,6 Fluoroscopy is used in all
left atrial procedures to help identify the location of the mapping and ablation catheters and to help navigate them through the atrium to the appropriate site for ablation. In the present study, we demonstrated the feasibility of registering a 3D left atrial CT model with fluoroscopic images of the left atrium. By allowing contrast differentiation between the left atrium and the PVs, the registered model revealed the exact location of the mapping and ablation catheters, the PVs, and the left atrium separate from other cardiac structures. In addition, the use of fluoroscopy in conjunction with CT made it possible to perform and repeat the registration process quickly and efficiently. This may prove useful because it allows real-time visualization of anatomic structures while still taking advantage of the more accurate and extensive images obtained by CT scanning. The combination of 3D CT models with projection images of fluoroscopy may thus have significant clinical implications in the treatment of cardiac arrhythmias, allowing for more accurate tracking and location of the mapping and ablation catheter.

Phantom Studies

The use of the phantom studies with beads demonstrated that accurate registration between the 2 modalities is possible. Because the phantom is a rigid body, studies using a phantom model were helpful in identifying any rotational errors due to any improper position of the phantom during the imaging sequences. Rotational errors due to differing orientations of the phantom model during CT imaging and fluoroscopy could be identified and corrected by rotating the CT left atrial model. Any correction made by rotating the CT image proved quite easy to perform on the workstation platform used for registration. A process currently in use adjusts the CT image automatically to the fluoroscopic orientation, which further eases orientation of the CT image to the x-ray. The coronary sinus catheter location in respect to the patient’s table was used to make an appropriate scaling factor calibration between the 2 systems. In Figure 2, blue lines across the superior vena cava in A and B confirm that the superior vena cava is the same width in both modalities, which suggests that both fluoroscopic and CT images are calibrated. However, the catheter configuration is different between the CT and the fluoroscopic image (red arrow). This change in the configuration of the catheter could be due to rotational error. In Figure 2C, the catheter orientation is corrected by rotating the CT image 7° in a right anterior oblique direction. However, as shown by the yellow arrows, the images are still not oriented properly. Thus, the discrepancy between the modalities in the configuration of the catheter is not due to rotation but rather to catheter movement between the imaging modalities. This would not be important clinically, however, because registration is performed virtually simultaneously with fluoroscopy.

CT-Fluoro Registration in Patients

Intrasubject registration becomes a matter of translating and rotating one of the image volumes with respect to the other until the maximum level of similarity has been reached between the 2 modalities. The precision with which the anatomic landmarks correspond to each other determines registration accuracy. As shown in the phantom studies, it is possible to calibrate the 2 images. Similarly, the magnitude of any real or apparent rotational errors between the CT image and the fluoroscopic image can be identified and corrected. However, unlike the phantom, which is a rigid body, rotational errors in the patient model could occur due to cardiac motion and respiration. The cardiac motion error can be corrected by obtaining the fluoroscopic images during the same phase of the cardiac cycle as was used for segmentation reconstruction of the left atrium. Thus, it is possible to synchronize the 2 systems with respect to the cardiac phase. It was possible to correct further rotational errors by moving the registered CT image to align with fluoroscopy markers such as the location of the multielectrode basket catheter and contrast-filled PVs. Unlike the phantom model, however, there is no other quantitative information that can be used to assess overall efficacy of registration in patients.

Study Limitations

Heart rhythm changes and the possibility of a change in chamber dimensions between CT imaging and fluoroscopy could potentially affect registration. Thus, registration accuracy could potentially be enhanced if the patient is in the same rhythm at the time of imaging and registration and if registration is performed shortly after the time of imaging. However, we did not see many inconsistencies during registration of the 3 patients who were in AF at the time of imaging and in sinus rhythm at the time of registration. Obtaining fluoroscopic images during the same phase as CT reconstruction of the left atrial images is obtained (eg, diastole) should prevent errors due to cardiac motion. Any persisting errors could be further corrected by superimposing the contrast-filled PVs and the coronary sinus over the registered image. Craniocaudal movement of the heart is known to occur during spontaneous respiration. Some rotational error can be attributable to this. Similar to cardiac
motion, synchronization of images to the same phase of the respiratory cycle is one possible approach to correcting this problem.

Conclusions
CT-fluoro registration of the left atrium is feasible. Clinical availability of a combination system could be important in directing appropriate therapy for left atrial arrhythmias.

Disclosures
Melissa Vass and Barry Belanger are employees of GE Healthcare in Waukesha, Wis. Elisabeth Soubelet and Regis Vaillant are employees of GE Healthcare in Buc, France. Dr Sra has a research agreement with and has served on the Advisory Board of GE Healthcare. There are no conflicts of interest to disclose for the remaining authors.

References
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