Intracardiac echocardiography for registration of rotational angiography-based left atrial reconstructions: a novel approach integrating two intraprocedural three-dimensional imaging techniques in atrial fibrillation ablation

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Aims
Image integration of three-dimensional (3D) reconstructions of left atrial (LA) and pulmonary vein (PV) anatomy into electroanatomical mapping (EAM) plays a major role in atrial fibrillation (AF) ablation. Point-by-point EAM is commonly used for registration of imported LA and PV anatomy. We aimed to assess the accuracy of intraprocedural rotational angiography-based LA imaging registered by spatial reconstruction of intracardiac echocardiography (ICE) in patients undergoing AF ablation.

Methods and results
Twenty-two patients (11 males, 6.6 ± 12 years) were studied. Reconstructions of LA and PVs based on rotational angiography were registered by a second 3D reconstruction based on ICE. In a second step, EAM points were added to ICE 3D reconstructions. A 3D image of the LA and PVs was reconstructed in all patients by both imaging modalities. Rotational angiography and ICE-based LA 3D reconstructions took 11.5 ± 5.2 and 20.4 ± 11.2 min, respectively. A total of 17 ± 6 two-dimensional ICE fans were used for spatial reconstruction of ICE. The deviation between the two 3D shells was 2.6 ± 0.5 mm. Integration of 78 ± 58 EAM points into ICE 3D reconstruction did not significantly reduce the deviation to rotational angiography-based reconstructions (2.7 ± 0.6 mm). All PVs were isolated successfully.

Conclusions
Intraprocedural 3D reconstruction of LA and PVs for ablation of AF is feasible based on both rotational angiography and ICE. LA reconstructions based on rotational angiography can accurately be registered using 3D ICE shells. Additional EAM does not enhance accuracy. Therefore, registration of rotational angiography-based 3D reconstructions by 3D reconstructions from ICE seems to be an alternative technique to support AF ablation.

Keywords
Atrial fibrillation • Pulmonary vein isolation • Catheter ablation • Intracardiac echocardiography • Rotational angiography

Introduction
Catheter ablation is an established treatment option for patients with symptomatic atrial fibrillation (AF).1,2 Radiofrequency current is still the most widespread energy source applied. Integration of three-dimensional (3D) reconstructions of pre-procedurally acquired data sets derived from computed tomography (CT) or magnetic resonance imaging (MRI) into electroanatomical mapping (EAM) systems has been introduced to guide left atrial (LA) ablation procedures.3–10 Although data on the benefit of

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image integration into EAM in terms of procedural success and radiation burden are not uniform, this technique has been adopted by many centres. Registration of pre-procedurally acquired data sets is traditionally performed by intraprocedural EAM in a point-by-point manner. Recent data favour intracardiac echocardiography (ICE) as an alternative tool for registration of pre-procedural imaging. This may avoid registration errors originating from active deformation of the LA evoked by the mapping catheter and may have the additional benefit of shorter dwell times of sheaths and catheters within the left atrium, since mapping can be performed with the ICE probe placed in the right atrium. However, additional registration of EAM points may cover areas not well reflected by ICE and thereby increase the accuracy of a solely ICE-based reconstruction. Intraprocedural imaging techniques based on a computed C-arm rotational angiography may be superior to pre-procedural imaging techniques in terms of actuality and may further improve clinical workflow. Image integration of this novel modality is currently achieved by point-by-point EAM and therefore may also be biased by LA deformation induced by the ablation catheter itself.

Registration of intraprocedural rotational angiography-derived imaging by non-contact LA mapping may overcome registration errors originating from mapping tool-based LA deformation. Moreover, this technique might avoid inaccuracy due to anatomical changes between imaging and the procedure itself. The aim of our study was to evaluate the feasibility of a rotational angiography-based reconstruction registered by a 3D ICE reconstruction of the LA. Furthermore, we studied the potential benefits obtained by integration of additional EAM on the accuracy of 3D reconstructions derived from ICE.

Methods

Study population
We included patients assigned for ablation therapy of symptomatic, drug refractory paroxysmal, or persistent AF. Antiarrhythmic drugs were discontinued at least three half-lives before the procedure with the exception of amiodarone, which was discontinued at least for 3 months. Phenprocoumon was discontinued until normalization of the international normalized ratio and replaced by fractionated heparin. All patients provided informed written consent for this study.

Procedural description
Patients underwent pre-procedural transesophageal echocardiography to rule out LA thrombi. Transthoracic echo was performed to assess LA diameters and left ventricular ejection fraction utilizing the Teichholz method. A decapolar catheter (Supra CS, Biosense Webster, Diamond Bar, CA, USA) introduced from the left subclavian vein was placed in the coronary sinus. A bolus of 10 000 units of heparin was given intravenously after the transseptal puncture; subsequently, bolus injections of heparin were administered to maintain an activated clotting time of >350 s. Two transseptal sheaths (8 and an 8.5 Fr Mullins sheath, St Jude Medical, St Paul, MN, USA) were placed in the LA via right femoral access. A 10-pole circumferential mapping catheter (Lasso™, Biosense Webster, Diamond Bar, USA) was advanced into the LA via the 8 Fr transseptal sheath and successively placed in the antra of all pulmonary veins (PVs) to guide radiofrequency current delivery. Pulmonary vein isolation (PVI) was confirmed by entrance block occurring during ablation using an 8 Fr open irrigated tip ablation catheter (Navistar Thermocool f-curve, 3.5 mm, Biosense Webster, Diamond Bar, CA, USA) advanced into the LA via the 8.5 Fr sheath. A saline flow of 30 ml/min was chosen at a maximum energy of 50 W; ablation temperature and lesion duration were limited to 48°C and 20 s, respectively. The ablation settings were not adjusted to the area of ablation. A 10 Fr ultrasound catheter (Soundstar, Biosense Webster, Diamond Bar, CA, USA) was inserted via a short 11 Fr sheath placed in the left femoral vein to guide transseptal punctures as well as placement of the circumferential mapping catheter in the PV antra. The position of the oesophagus was continuously monitored by ICE. Ablation was guided by visualization of the ablation catheter in the surrounding of the imported rotational angiography-based shell within the CartoMerge system and by real-time ICE.

Intracardiac ultrasound imaging and electroanatomical mapping
Prior to radiofrequency energy delivery, 3D anatomical shells of the LA (Figure 1), PVs, LA appendage, and oesophagus were reconstructed with two-dimensional ICE images. A novel mapping system allowing for image integration of ICE and EAM (CartoSound, Biosense Webster, Diamond Bar, CA, USA) was used. A navigation sensor embedded within the ultrasound catheter (SoundStar, Biosense Webster) permits detection of the position and direction of the ICE probe. Electrocardiogram (ECG)-gated images of the LA and associated anatomical structures were acquired with the ICE catheter placed in the right atrium before transseptal puncture and placement of sheaths in the LA during shallow breathing. The body surface ECG was used as a reference to provide ECG gating in patients in
AF during image acquisition, whereas an intracardiac atrial signal from the coronary sinus was used in patients in sinus rhythm. ICE was performed using a portable ultrasound system (Cypress, Siemens Medical Solutions, Erlangen, Germany) allowing online transmission of the ICE data to the mapping system. Contours of LA and adjunctive structures were traced automatically with manual corrections, whenever automatic tracing was inaccurate. Contours were then assigned to different maps representing the different anatomical structures visualized by the ICE. According to the discretion of the operator, additional EAM mapping points were added to the 3D shell of the LA derived from ICE imaging to optimize spatial resolution.

Rotational angiography-based imaging

The technique of 3D LA and PV reconstruction using cardiac C-arm CT has been previously described. Briefly, LA was centred in a posterior–anterior and in a lateral C-arm position by table movements. Pulmonary transition time was estimated by a test bolus injection of 20 mL of contrast media with a flow rate of 20 mL/s into the main pulmonary artery. Image acquisition was then started with delay of 20 mL of contrast media with a flow rate of 20 mL/s into the main pulmonary artery. Image acquisition was then started with delay of the pulmonary transition time following administration of 84 mL of contrast media (Ultravist 370, Bayer-Schering GmbH, Berlin, Germany) into the main pulmonary artery via a standard 6 Fr pigtail catheter with a flow rate of 15 mL/s using an automatic power injector. Rotational angiography along a circular 198° arc (99° right anterior oblique to 99° left anterior oblique view) was performed within 5 s with an Artis C-arm system (Siemens, Erlangen, Germany). A large focus was used with preferred 70 kVp, automatic exposure control, and system dose 0.54 μGy/pulse. Two hundred and forty-eight projection image data were collected at 60 frames/s by a 30 × 40 cm flat-panel detector with 4 × 4 pixel spacing achieving a pixel size of 600 × 600 μm. The rotational angiography was performed in breath hold with arms positioned above the patient’s head. The acquired data were automatically transmitted to the syngo® X-workplace by the Artis Imaging System (Siemens, Erlangen, Germany). Three-dimensional images were reconstructed by the DynaCT Cardiac software (Siemens, Erlangen, Germany), including correction methods such as truncation, beam hardening, and scatter correction. The surface of the LA was depicted by a computer-aided one-click segmentation (syngo® Inspace EP at the syngo® X-workplace, Siemens, Erlangen, Germany); if necessary, the segmentation could be corrected by manually adding some strokes to the 3D reconstruction.

Image integration and registration

The process of image integration of rotational angiography-based 3D reconstructions of the LA into EAM systems has been described previously. Briefly, image data sets of the segmented LA derived from rotational angiography were transferred to the EAM system (CartoMerge, Biosense Webster Inc., Diamond Bar, CA, USA) via compact disc and integrated without further segmentation. The timing reference of the EAM system was set equivalently to the reference chosen for registration of the ICE images. The 3D syngo® DynaCT Cardiac anatomy was displayed on the Carto screen, and the CartoMerge procedure was conducted. Under ICE guidance, a single EAM landmark point was set at the superior part of the ostium of the left superior PV. The corresponding point on the integrated syngo® DynaCT Cardiac surface of the segmented LA was marked (‘landmark registration’), and then both marker points were matched by an integrated visual alignment software algorithm integrated in the CartoMerge technology. Finally, a surface registration algorithm, which is also part of the CartoMerge technology, was performed to best fit the 3D shell derived from ICE and the syngo® DynaCT Cardiac surfaces. In a second step, EAM points were added to the ICE shell and registration was repeated.

Data analysis and follow-up

Continuous and discrete variables were reported as mean ± standard deviation (SD) and percentages (%), respectively. The distances of all points on the 3D ICE shell and corresponding points on the LA syngo® DynaCT Cardiac surface were calculated by software integrated in the CartoMerge system (Figure 2). The average integration error for registration by 3D ICE shells was compared with the average integration error for registration by 3D ICE shells and additional EAM points using Student’s t-test for paired samples or Mann–Whitney U test when normal distribution could not be assumed. P-values <0.05 were considered significant. All statistical analyses were performed using SPSS 16.0 software (SPSS Inc., Chicago, IL, USA).

Follow-up was performed at 3, 6, 9, and 12 months after ablation. Patients were seen for an outpatient clinical visit including an ECG, a Holter ECG, and an interview.

Results

Patients

The study population consisted of 22 patients. Patient characteristics are detailed in Table 1.

Intracardiac echocardiography imaging

Left atrium, LA appendage, oesophagus, and PVs could be visualized in all patients based on two-dimensional ICE (Figure 3). A 3D reconstruction of the LA and adjunctive structures was feasible in all patients within 20.4 ± 11.2 min. A total of 17 ± 6 two-dimensional (2D) echo planes were recorded to create a 3D shell based on ICE. Sole automatic tracing accurately traced the endocardial LA surface in 83 (22%) planes, whereas 193 (52%) planes needed manual optimization. Complete manual tracing of the endocardial surface was required in 98 (26%) planes.

Rotational angiography imaging

Complete reconstructions of LA and proximal PVs were feasible in all patients with a single injection of contrast media into the pulmonary artery for rotational angiography. A total of 11.5 ± 5.2 min was needed for acquisition and segmentation of LA and PVs. In 16 (73%) patients, single-click segmentation featured by the syngo® DynaCT Cardiac software allowed a complete 3D visualization of the LA with all PVs and the LA appendage in one step. In these cases, no further processing was necessary. In the remaining six patients, one PV (n = 4) or two PVs (n = 2), or one PV and the LA appendage (n = 1) were clearly depicted in the rotational angiography-based CT, but not chosen for segmentation by the syngo® DynaCT Cardiac software. Thus, they had to be labelled manually and added to the 3D surface by a recalculation of the single-click segmentation.
Intracardiac echocardiography-guided image integration of syngo® DynaCT Cardiac

Integration of rotational angiography-based 3D reconstructions of the LA using a 3D shell derived from ICE imaging was feasible in all patients. A single landmark point was taken in all patients at the superior aspect of the left superior PV. In 17 patients (77%), operators added EAM points to ICE-derived 3D shells aiming to improve spatial resolution.

The registration error between the ICE shell and the 3D reconstruction derived from rotational angiography was 2.6 ± 0.5 mm, if no additional EAM points were registered and integrated into the 3D ICE shell. Integration of an additional 78 ± 58 EAM points into ICE 3D reconstruction did not significantly change the deviation to rotational angiography-based reconstructions in these patients (2.6 ± 0.5 to 2.7 ± 0.6 mm, P = n.s.).

Procedural data and clinical outcome
The total skin-to-skin procedure time was 210 ± 42 min. The total fluoroscopy time and radiation dose were 61 ± 25 min and 7268 ± 3833 μGy m², respectively. All PVs could be isolated confirmed by entrance block. No acute procedural complications occurred. In particular, there was no clinical evidence for
thromboembolic events. Three patients were lost to follow-up. At a mean follow-up of 3.25 ± 0.6 months, 68.4% of the remaining study patients were free from recurrence of atrial tacharrhythmias.

Discussion

Main findings

To the best of our knowledge, this is the first study reporting on integration of two intraprocedural non-contact 3D imaging techniques in ablation of AF. Registration of rotational angiography-based 3D reconstructions of the LA in an EAM system by 3D shells derived from intraprocedural ICE was demonstrated to be feasible within a short time frame. No beneficial effects of additional EAM mapping on registration errors were found.

Rotational angiography-based left atrial imaging

Several studies reported on the opportunity to replace preprocedural imaging, commonly performed as an MRI or CT, by 3D reconstructions based on rotational angiography. Intra-procedural imaging of the LA is regarded to be superior in terms of actuality and might be advantageous in improving clinical workflows. Our data show that reconstruction of the LA and adjunctive structures is feasible with high image quality, and without a need for repeated imaging or image fusion of parts of the LA. This is well in line with other studies using a large (30 × 40 cm) flat panel detector and a frame rate of 60/s. The time for acquisition and 3D reconstruction of the LA was 11.5 ± 5.2 min, which is comparable to earlier results of our group and others.

Intracardiac ultrasound imaging

Three-dimensional reconstruction of anatomic structures using ICE images was feasible in all patients. Creating a 3D shell of the LA from multiple 2D ICE images took 20.4 ± 11.2 min. This is comparable to the results reported by Singh et al. for reconstruction of the LA from a right atrial ICE probe position. Others reported longer times for image acquisition and LA reconstruction (76 ± 27, 51 ± 25, and 39 ± 12 min, respectively). These differences may be traced back to a higher number of ultrasound contours used for LA rendering in those groups, which is likely to be more time consuming than our approach.

Registration of three-dimensional shells based on rotational angiography by three-dimensional ultrasound reconstructions

In our study, 3D shells from the LA derived from ICE were implemented as an intraprocedural imaging technique for registration of a second imaging technique; this is in contrast to others, who used the ultrasound imaging technique itself as an environment for the ablation procedure. A similar technique has been reported by Singh et al., who merged pre-procedural CT/MRI, and den Uijl et al., who merged pre-procedural CT. However, in our study an intraprocedural rotational angiography-based 3D reconstruction of the LA was merged. Registration of rotational angiography-based 3D reconstruction in an EAM system has been described by our group, but in our former study point-by-point EAM had been used for registration. Therefore, registration of rotational angiography-based imaging using ICE reconstruction is a novel approach.

While our image integration mode was feasible in all patients studied, we found a registration error of 2.6 ± 0.5 mm between the ICE shell and the 3D reconstruction derived from rotational angiography. This is comparable to the findings of Singh et al., who reported a registration error of 2.52 ± 0.58 mm when the ICE probe was placed in the right atrium and a pre-acquired MRI or CT was registered by the ICE-created anatomic shell. Den Uijl et al. reported a registration error of 2.2 ± 0.3 mm for integration of a CT scan. Since the accuracy of rotational angiography imaging is known to be similar to CT, what accounts for this difference remains unclear. While in our study 17 ± 6 ICE planes were used to reconstruct the LA, den Uijl et al. used 31.1 ± 8.5 contours. This may be a reason for the difference; however, the optimal number of contours needed is not known. Noseworthy et al. reported on the pivotal role of respiration in the accuracy of image registration in EAM. Therefore, image acquisition may be disturbed by ongoing shallow breathing, contributing to the slightly elevated registration errors in our study. However, registration during ongoing breathing might better reflect the relation between cardiac anatomy and imported LA surfaces as it is found during ablation procedures, whereas breath-hold imaging represents a more artificial condition.

Moreover, integration of 78 ± 58 EAM points into ICE 3D reconstruction did not significantly reduce the deviation to rotational angiography-based reconstructions (2.7 ± 0.6 mm). This makes it even more likely that respiration conditions may have disturbed registration rather than imaging quality of either rotational angiography or ICE.

Furthermore, ICE was registered in an ECG-triggered mode using either time of atrial ECG or—in case of AF—time of QRS, while rotational angiography was registered in an untriggered mode. This may also have contributed to the registration error. ICE has been adopted by many physicians to guide all their AF ablation procedures, and the addition of 3D reconstruction capabilities only means a limited increase in costs if ICE is in use anyway. However, before adding the costs of ICE for registration of rotational angiography-based LA reconstructions, a comparative study with and without ICE may be requested. Therefore, this study is a stepping stone for a future study evaluating conventional integration mapping vs. 3D angiography and 3D ICE mapping for AF ablation, with short- and long-term outcomes.

Procedural data and clinical outcome

The total skin-to-skin procedure time was found to be 210 ± 42 min in our study. This is well in line with what other groups reported for AF ablation procedures using image integration of pre-procedural imaging. The fluoroscopy time was 61 ± 25 min, which is within the range of fluoroscopy times reported by others. However, in our study not only intraprocedural imaging was added to total procedure time but also
integration of EAM, and ICE-based LA and PV reconstruction was performed and contributed to procedural duration. Furthermore, rotational angiography—replacing pre-procedural imaging—leads to additional fluoroscopy time and intraprocedural radiation exposure. Therefore, fluoroscopy time and procedure time seem to be comparatively short. Complete avoidance of additional EAM might not only further reduce procedure time and fluoroscopy exposure but also decrease the risk for thromboembolic events due to reduced LA dwell time. However, due to the limited number of study patients, this conclusion cannot be drawn from the absence of thromboembolic events in our study population.

Although no direct comparisons were made to other imaging techniques in terms of procedural outcome in our study, our finding of freedom from atrial tachyarrhythmias in 68.4% of the study patients seems to be comparable to the clinical outcome found in other studies applying image integration in AF ablation procedures.5,7,10–12

Limitations

The number of patients included in our study was limited. Furthermore, this was an acute study on PVI not powered to validate long-term effects and clinical outcome. Ultrasound imaging was limited to a right atrial position of the ICE probe, and this may have led to suboptimal imaging quality. This was an observational study and no direct comparison to alternative registration and imaging techniques has been made.

Conclusion

Intraprocedural 3D reconstruction of LA and PV for ablation of AF is feasible based on rotational angiography and ICE. Deviation between the two modalities is acceptable and cannot be further reduced by integration of additional EAM points into the 3D ICE reconstructions. Registration of LA reconstructions based on rotational angiography by ICE 3D reconstructions is a novel registration technique and might replace the current strategy of registration by point-by-point EAM of the LA.

Conflict of interest: G.N. received honoraria for lectures from Siemens AG and Biosense Webster Inc. Klinikum Coburg has a corporate appointment with Siemens AG.

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Images in Electrophysiology

Complete heart block?

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This patient was admitted 3-months post-orthotopic heart transplantation (biatrial anastomosis) with the following electrocardiogram (ECG). The anastomosis resulted in electrical isolation of the recipient atrium from the donor heart (recipient P-waves are dissociated from the donor P-waves and QRS). The ECG demonstrates P-waves of two different morphologies and rates (recipient/donor atria), P-waves from the recipient atrium during atrial fibrillation (AF) in the donor atrium, and non-conducted P-waves from the recipient atrium following termination of AF (sinus arrest of the donor atrium). Sinus node dysfunction of the donor atrium can produce the appearance of complete heart block.

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