The Role of Three-dimensional Rotational Angiography in Atrial Fibrillation Ablation

Georg Nölker, Dieter Horstkotte and Klaus-Jürgen Gutleben

Department of Cardiology, Heart and Diabetes Center North Rhine-Westphalia, Ruhr University Bochum, Bochum, Germany

Abstract

Three-dimensional (3D) imaging became the cornerstone of catheter guidance in atrial fibrillation (AF) ablation procedures during the last few years. Multislice computed tomography (MSCT) and magnetic resonance imaging (MRI) have been the technologies of choice for pre-procedural imaging of the left atrium (LA) and the pulmonary veins to make lesions more precisely set in a highly variable and difficult to understand 3D environment. These technologies have been used not only for pre-procedural orientation but have also been overlayed to fluoroscopic views in many fluoroscopy-guided ablation procedures. As image integration into non-fluoroscopic 3D imaging systems became available, 3D reconstructions of MSCT and MRI became the standard approach in many centres. However, 3D imaging is not a cornerstone during ablation as it is not indispensable and ablation can be performed without. Although rare, some very important and key centres do not routinely use 3D imaging during ablation. Being remote to the ablation procedure, these imaging technologies may have the disadvantage of not reflecting the current status of a variable LA volume and scheduling of an additional diagnostic procedure may complicate the workflow of AF ablation procedures. Intra-procedural imaging techniques are likely to overcome both issues. Beside others, rotational angiography has been introduced for proving highly actual imaging by intra-procedural acquisition of 3D shells suitable for overlay to fluoroscopy without need for registration and image integration into 3D mapping systems registered by point-by-point electroanatomical mapping or 3D echocardiographic imaging.

Keywords

Atrial fibrillation, pulmonary vein isolation, catheter ablation, intracardiac echocardiography, image integration, rotational angiography

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Correspondence: Georg Nölker, Department of Cardiology, Heart and Diabetes Center North Rhine-Westphalia, Ruhr University Bochum, Georgstrasse 11, 32545 Bad Oeynhausen, Germany. E: gnoelker@hdz-nrw.de

Catheter ablation is an established treatment option for patients with symptomatic atrial fibrillation (AF).^{1–3} Pulmonary vein (PV) angiography has been the initial imaging tool in AF ablation and is still used by up to 50 % of leading electrophysiologists.³ PV angiography still plays a major role in balloon-based ablation techniques routinely performed without electroanatomical mapping (EAM). Some very experienced centres do not feel any need for three-dimensional (3D) imaging due to their ability to orientate in two-dimensional (2D) fluoroscopic views. 3D imaging is likely to better reflect relations between anatomic structures and ensures that all PVs are clearly identified. Therefore, it is not surprising that the majority of studies done on image integration of 3D shells into EAM show positive effects on radiation exposure, procedural and long-term success.^{4–6} In particular, results of large multicentre registries clearly show the benefit of image integration regarding freedom from AF⁷ in comparison with fluoroscopy-guided ablation. Integration of 3D reconstructions of pre-procedurally acquired data sets derived from multislice computed tomography (MSCT) or magnetic resonance imaging (MRI) into EAM systems has been introduced to guide left atrial (LA) ablation procedures.^{8–13} However, these remote imaging technologies may not perfectly reflect the status found during ablation due to changes in cardiac rhythm and preload, and their impact on the LA volume for example. Therefore, the search for an intra-procedural technology close to realtime imaging continued and led to the development of rotational angiography.

Principles of Rotational Angiography

Different protocols of this technique have been introduced over time^{14–19} having in common the principle of a C-arm run around the patients' region of interest (in case of AF ablation the LA) with acquisition of X-ray images with a certain rate of frames per second using a flat panel detector (see *Figure 1*). To enhance cardiac structures, contrast media is administered into the right atrium or the pulmonary artery and C-arm run is started after a delay reflecting the pulmonary transition time. Individual pulmonary transition time can be estimated by a bolus injection of contrast media into the pulmonary artery. This compensates for delayed enhancements due to low cardiac output. Alternatively, direct injection into the LA is performed and the C-arm run is started with a short delay. A more intense contrast of the LA may be seen after direct injection. However, contrast injection into the LA may lead to an artificial enlargement of its image. For enhancement of the oesophagus the patient is asked to swallow contrast paste. All these approaches provide data sets that allow for measurements in virtually unlimited planes and 3D reconstruction of the LA, PV, aorta and the oesophagus applying software on different specialised computer systems (e.g. Syngo X-Workplace, Siemens, Forchheim, Germany and EP Navigator, Philips, Best, The Netherlands).

Accuracy in Comparison with Multislice Computed Tomography

Accuracy is a critical point of imaging during AF ablation as ablating too far ostially bears the risk of inducing PV stenosis and of missing

antral foci, and overseeing small PVs may lead to ineffectiveness of the procedure. Furthermore, suboptimal orientation may lead to perforation and other avoidable complications. The gold standard of 3D imaging in AF ablation is MSCT. Two studies have compared accuracy of MSCT with rotational angiography. In our study,¹⁶ planes from pre-procedural MSCT and DynaCT Cardiac (Siemens AG, Forchheim, Germany) were automatically parallelised and cross-sectional diameters of PVs, LA appendage and LA and aorta were correlated. In our series we found an overall correlation of diameter of 0.99 and no significant difference in diameters derived from rotational angiography and MSCT. However, although not being significantly different between the two modalities, correlation between pre- and intra-procedural volumes of the LA was less good (0.86). This may be due to the remoteness of MSCT as discussed above. In addition, the position of the oesophagus may also vary significantly between a pre-procedural and thereby remote imaging and an intra-procedural rotational angiography supporting the assumption that higher actuality of imaging is relevant. However, intra-procedural changes of structures and positions remain a domain of realtime imaging technologies. Kriatselis and co-workers²⁰ showed later that acceptable imaging in comparison with MSCT can also be achieved with a smaller detector. In their data set a correlation of 0.82–0.92 for the PVs and 0.80–0.87 for the LA volume was found.

Three-dimensional Reconstructions of Rotational Angiography as an Overlay to Fluoroscopic Views

Having a 3D reconstruction of the LA and the PV available for pre-procedural orientation was found to be helpful but was only a stepping stone towards image integration. The first step of image integration was to superimpose 3D reconstructions to fluoroscopic views during the ablation (see Figure 2). Technologies are available to make the superimposed 3D shell automatically follow moves of the C-arm to provide a continuous 3D guidance to the operator (e.g. Syngo iPilot dynamic, Siemens, Forchheim, Germany). As image acquisition by rotational angiography is performed with the patient at the same place where ablation is done, no registration or adjustment of the reconstruction is needed as long as the patient does not move.¹⁶ In case of need for registration due to movements, protocols have been introduced to facilitate this based on the position of the LA related to the spinal column and the trachea and mainstem bronchi.²¹

A limitation of the overlay technology still is the missing compensation for respiration. However, the overlay technique can be used as a single navigation tool in AF ablation¹⁷ with an acceptable short-term outcome and low complication rates. Meanwhile, superimposition of ablation points to fluoroscopy and rotational angiography has been integrated into software of different manufacturers. This may reduce the need for EAM systems furthermore, as long as advanced functionality like activation mapping is not required. Ablation then is fully fluoroscopy-based and by this radiation exposure due to long fluoroscopy times may be high.^{17,22}

Image Integration of Rotational Angiography into Three-dimensional Mapping Systems

Image integration of 3D shells into EAM-systems has lots of theoretical advantages over overlay techniques. In particular, activation mapping in case of transformation of AF into atrial tachycardias is possible; navigation in a 3D environment can be performed without or with a minimal amount of additional radiation and parameters like contact-force can be related to ablation points in the EAM. Moreover, it has

Figure 1: Image Acquisition in Rotational Angiography

The upper row of images (A–F) shows the continuous movement of the C-arm along a 198° arc from 99° right anterior oblique (A) to 99° left anterior oblique (F) within five seconds. Notably, the patient is positioned with his arms above his head and is asked for breathhold for optimal imaging quality. The lower row of images (G–L) shows the corresponding X-ray images at each angiographic position of the C-arm. 248 projection image data are collected at 60 frames per second by a 30 x 40 cm flat panel detector with 4 x 4 pixel spacing achieving a pixel size of 600 x 600 micrometre (µm).

Figure 2: Section of a 3D Reconstruction Derived from a Rotational Angiography is Depicted in Red as an Overlay to a Fluoroscopic View. The Circumferential Multipolar Mapping Catheter ('Lasso') has been Inserted into the Right Superior Pulmonary Vein

ICE = intracardiac echocardiography.

been shown that integration of 3D reconstructions into EAM may improve the outcome.¹³

Pre-procedural MRI and MSCT scans can be accurately registered to EAM-systems and integration of these has been the gold standard of image integration for a long time. Integration of the rotational angiography-based reconstructions is likely to have the same advantages of MRI/MSCT integration and may be even superior because of its high degree of actuality and its seamless integration into the workflow in the electrophysiology laboratory. 3D reconstructions of the rotational (see Figure 3) angiography can be transferred to both the EnSite (St Jude Medical) and the Carto® (Biosense Webster, Inc) system either directly online via hospital networks or via hard copies in terms of a compact disc (CD). Image integration of rotational angiography then follows the same steps well-known for MSCT/MRI, and accuracy of imaging compared with MSCT has been demonstrated to be acceptable with a deviation between EAM and rotational angiography of 2.2 ± 0.4 millimetres (mm).²³ 3D reconstructions of intracardiac echo may serve as an alternative to EAM for integration of rotational angiography. This can be done before LA access and thereby LA dwelling time is reduced and inaccuracy of EAM due to pushing a mapping catheter against the LA wall may be reduced.²⁴ This technique is also very accurate in

Figure 3: 3D Reconstruction of a Rotational Angiography (DynaCT Cardiac, Siemens, Forchheim, Germany) of the Left Atrium and Pulmonary Veins (Depicted in Grey) Integrated and Registered in a 3D Mapping System (EnSite Velocity, St Jude Medical, Sylmar, CA, US) in a Posterior View

Colours on the shell symbolise local activation times of a macro-reentrant tachycardia from earliest to latest colour-coded in white over red and green to purple. Red dots represent ablation points in an early-meets-late zone where the tachycardia terminated during ablation. The tip of the ablation catheter can be seen in green close to the ablation points. The coronary sinus catheter (CS) is depicted in yellow.

registration of an intra-procedural shell by another one and additional EAM points do not improve registration accuracy.

Radiation Exposure by Rotational Angiography

Rotational angiography as an X-ray-based imaging system is potentially harmful for the operator and the patients. Radiation exposure has been reported to be 2.2 ± 0.2 to 6.6 ± 1.8 millisievert (mSv) based on estimations from the dose-area product.^{18,20,25} The huge variety of values may be traced back to different ways of estimation applied and to the different protocols used for image acquisition. However, comparisons to MSCT by some groups^{18,20} showed a significantly lower effective radiation dose in rotational angiography compared with MSCT. This is confirmed by our own unpublished data, finding 15.5 ± 10.1 mSv in patients with MSCT image integration compared with 9.0 ± 4.2 mSv in patients with rotational angiography ($p < 0.0003$) in terms of total procedural and pre-procedural effective doses. For sure, radiation exposure of MRI would have been zero and more recent MSCT protocols have demonstrated to save a lot of radiation. However, low-dose protocols for rotational angiography are under way. Radiation exposition to the operator can be minimised by initialising the C-arm run from the control room, this reduces the time of exposure to the time needed for placing the pigtail catheter and isocentering of the patient.

Time and Costs

In times of limited financial resources for healthcare even in the Western European and North American countries, besides its benefits, costs are a relevant matter of discussion. One group has calculated the costs of rotational angiography in terms of technical fee without personal costs and resulted in €91–95 per examination compared with €100–125 caused by a MSCT.²⁰ These are rough estimations and differences in workload will have an impact as well as variations in costs of different systems. However, rotational angiography does not seem to be costly in comparison with MSCT.

The time required for acquisition and segmentation of rotational angiography varies a little between different groups: Li et al.¹⁸

spent 14.4 ± 3.2 minutes and Kriatselis et al.¹⁷ reported on 6.0 ± 3.0 minutes for preparation and performance, 4.0 ± 2.0 minutes for 3D reconstruction and 5.0 ± 3.0 minutes and of a total time for acquisition and reconstruction of 13.0 ± 5.0 minutes in another series²⁰ being close to the times reported by Li et al. Our acquisition and reconstruction time seems to be shorter (7.0 ± 5.0 minutes) with a larger detector (30×40 centimetres [cm]; Siemens, Forchheim, Germany) at a frame rate of 60 per second, which is likely to improve imaging quality and thereby may reduce reconstruction time at the price of higher radiation exposure.¹⁶

Ways to Improve Imaging Quality in Rotational Angiography

Although X-ray systems with capability of rotational angiography have been installed in many electrophysiology laboratories in the last few years, use of these systems is still limited. This may be at least partly due to a learning curve in application of this novel technology, which may be shortened when a few key points are kept in mind.

Isocentering is of critical importance especially when a small detector is used. With a 20×20 cm detector, two landmarks may help the operator to isocenter:

- The tracheal bifurcation is always found some millimetres superior to the roof of the LA and closer to the right than to the left superior pulmonary vein in a posterior-anterior projection.
- The vertebral column is always at the back of the posterior wall of the LA in a lateral view and when half of it is depicted in the 20×20 cm detector in a lateral projection the LA is centred well.

Contrast can be improved by direct injection of contrast medium into the LA. This may have the disadvantage of longer LA dwelling time and will require either rapid ventricular pacing or adenosine to avoid an immediate washout of the dye. Both of these have their own disadvantages like induction of arrhythmias, need for general anaesthesia and others. In addition, administration of 50–60 millilitres (mL) of contrast medium into the LA while rapid ventricular pacing and/or adenosine is applied may lead to an artificial enlargement resulting in an overestimation of the LA volume by rotational angiography. Higher enhancing contrast medium may be another option to increase contrast (e.g. Imeron 400 MCT, Bracco Imaging, Konstanz, Germany with 400 milligram [mg] Iodine per mL). Any cables and skin electrodes have disturbing effects on X-ray imaging, removal of all these before image acquisition or use of X-ray transparent material improves imaging quality. A pigtail catheter filled with contrast medium after injection leads to imaging artifacts. This can be avoided by withdrawing the catheter after contrast medium administration or flushing the catheter with a few millilitres of saline. In case of working in a magnetic laboratory, the pigtail catheter can also be removed remotely by the Cardiodrive Catheter Advancement System (Stereotaxis Inc, St Louis, MO, US).

Limitations

In case of right-sided contrast injection, estimation of pulmonary transition time is of critical importance and may induce a learning period until this can be done properly.

Rotational angiography will always add a certain amount of radiation exposure to the procedure bearing a risk of inducing malignant diseases. Contrast enhancement is necessarily associated with administration of contrast media. This may be an issue in patients

with impaired renal function as well as in those suffering from severe congestive heart failure or thyroid dysfunctions. Finally, there is an undeniable but certainly very limited risk of anaphylactic reaction.

Conclusion and Perspective

Rotational angiography introduced as an imaging technology in AF ablation is highly accurate in displaying crucial structures

for PV isolation comparable with MSCT. Furthermore, being an intra-procedural imaging technique, it provides a high level of actuality and may improve workflows when scheduling of an additional imaging procedure can be avoided. Image-integration of 3D reconstructions based on rotational angiography into EAM is feasible, accurate and fast. Therefore, rotational angiography may replace other imaging technologies for AF ablation. ■

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