Imaging in electrophysiology

An electrophysiologists perspective on imaging by Andrew Thornton.

Sunninghill Hospital, Gauteng, South Africa

Address for correspondence:
Dr A.S. Thornton
PO Box 56
Magaliessig
2067
South Africa

Email:
andrewthornt@gmail.com

ABSTRACT **Imaging is becoming increasingly important in clinical cardiac electrophysiology. This article attempts to give a brief overview of what modalities we are presently using, those which may become important, and for what indications we may use them. In addition I will try and convince you why we should use some of them and what data is available concerning some of their potential advantages and drawbacks.** SAHeart 2008; 5:166-170

On reading the title of this article, some might ask why more imaging is needed than that supplied by a standard catheterization laboratory system, in other words by standard fluoroscopy. I will try to answer this in the next few paragraphs. Space unfortunately precludes an extensive review, but I will try to provide a sampler, if you will, of what imaging modalities are currently available or in development and how these might be able to assist us in the field of clinical cardiac electrophysiology (EP). I have concentrated on invasive cardiac electrophysiology and therefore will not generally consider imaging modalities for use in assessment of cardiac dyssynchrony and for optimization of resynchronization devices.

WHY DO WE NEED NEW IMAGING TECHNIQUES?

Standard fluoroscopy is a 2-dimensional (2D) imaging technique often requiring multiple views and the physician's imagination to "reconstruct" a 3-dimensional (3D) image in that physician's mind. X-ray at increasing doses increases the risk of malignancy and other complications related to ionizing radiation to those exposed to it, both patient and physician.[1]

In addition, electrophysiologists are tackling more and more complex procedures – those involving more complex anatomy, e.g. the left atrium and complex, often repaired, congenital heart disease, as well as more complex circuits, e.g. atypical atrial flutters, often after prior surgery or ablation procedures. Anatomic and electrical complexity often occur in the same patients.

The aims of the newer imaging techniques are varyingly to decrease radiation exposure to patient and physician, to improve efficacy of the procedures, and their outcome and safety, and to allow electrophysiologists to take on more complex procedures.

WHAT NEW IMAGING TECHNIQUES ARE AVAILABLE?

Newer forms of imaging can be divided into those obtained using modifications to standard fluoroscopy, such as rotational angiography, and those obtained preoperatively such as computed tomography (CT) and magnetic resonance imaging (MRI). There are also various imaging modalities obtained during a procedure, such as those obtained utilizing catheter movement – the so-called non-fluoroscopic mapping systems, those obtained using some form of ultrasound, such as transesophageal (TEE) and intracardiac (ICE) echocardiography, in either 2D or 3D form, and various forms of cardiac MRI, either intracardiac catheter-based MRI, or utilizing experimental MRI EP laboratories.

Rotational angiography

This uses high speed rotation of a C-arm in order to obtain CT-like images of vessels, such as the coronary sinus,[2] or more recently cardiac

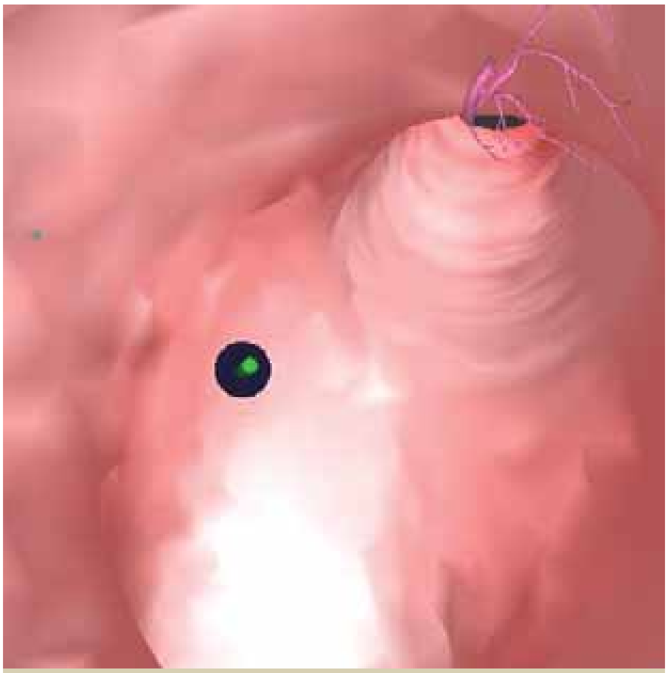

FIGURE 1: A virtual endoscopic view of the coronary sinus, going on superiorly, and a branch, going off inferiorly. Knowing how this side branch originates may be useful for accessing a particular branch.

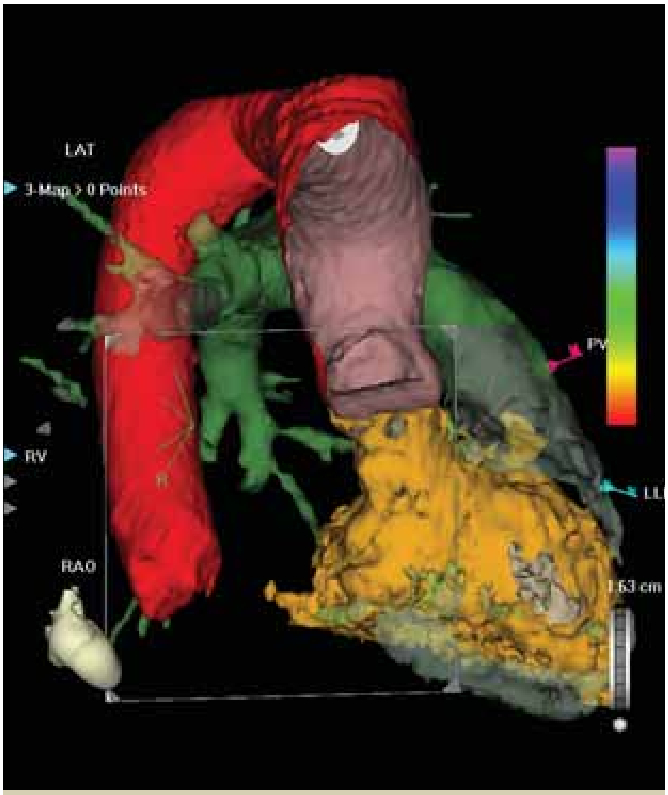

FIGURE 2: A reconstructed CT scan using CARTO Merge software. The software has assigned different colours to different chambers. In this case the left ventricle is yellow, the aorta red, and the right ventricular outflow tract (RVOT) and pulmonary artery are green. This image shows how the left ventricular outflow tract starts on the left side of the RVOT and curls behind it to end up on the right side of the pulmonary valve and main pulmonary artery.

chambers.[3] Both Siemens and Philips have versions of this, and the images can be overlaid onto standard X-ray screens or may be incorporated in the future into non-fluoroscopic mapping systems. These can in certain circumstances then be used to generate virtual endoscopic views of the vessel (Figure 1).

Pre-operative CT or MRI

Both pre-operative CT and MRI have been used for planning in a similar fashion to how this would be used for planning any other surgery.[4] They can be assessed in their standard sliced image configuration or after 3D reconstruction, which can allow for visualization of the entire chamber or can allow for cut-away or virtual endoscopic views (Figure 2). They allow planning, for example in the case of atrial fibrillation ablation, by allowing assessment of the number of pulmonary veins and whether there are common pulmonary vein ostia or extra pulmonary veins – essential when isolation of the veins is required. Aside from their use in each individual case, they have also taught us a great deal about real cardiac anatomy, perhaps even more so than cadaver dissection might have.

Non-fluoroscopic mapping systems

These allow the operator to make a model of the chamber of interest by moving a catheter around within that chamber. The different systems, CARTO (Biosense Webster, Diamond Bar, CA, USA) and EnSIte-NavX (St Jude Medical, St. Paul, MN, USA) use different systems to do this, but the end product is similar, a 3D model of the chamber (Figure 3).[5] Drawbacks to these systems are that a catheter or catheters need to be moved around in the chamber and the registration depends on the catheters reaching each corner of the chamber. In addition, the cardiac chambers are distensible and therefore these models can overestimate the size of the chamber. Once the anatomic model has been made, electrical information can be entered on this model. Examples of such information include electrical timing or activation detail, or registration of areas of special signals, for example complex fractionated electrograms which may represent areas in the case of atrial fibrillation which, when ablated, may be associated with better outcome. The maps can also be used to trace where ablation lesions have been placed.

Image fusion with non-fluoroscopic mapping systems

Image fusion uses anatomic information obtained pre- or intra-operatively to fuse with an anatomic model made with the use of non-fluoroscopic mapping systems so as to obtain a better representation

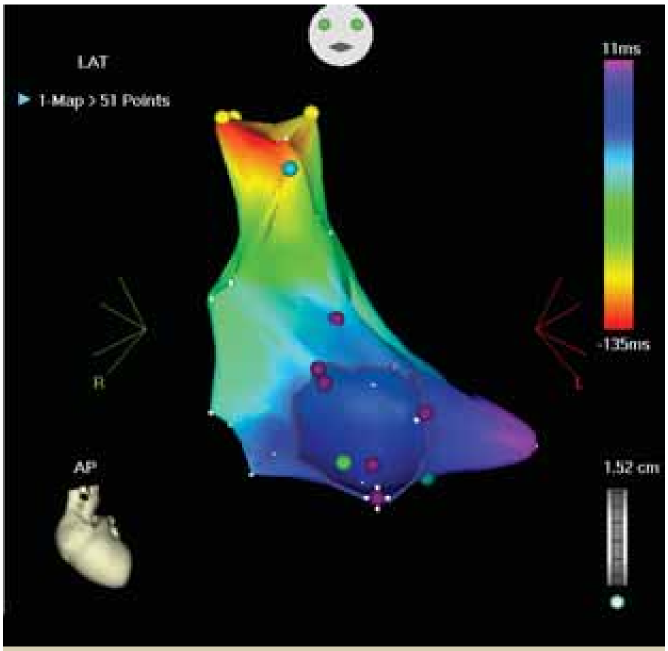

FIGURE 3: A CARTO activation map of the right atrium in an antero-posterior view with the tricuspid valve facing towards us. Earliest activation in red is within the superior vena cava and spreads towards the latest activation – the purple at the lower right of the picture.

of the true anatomy of a chamber. This should allow for improved accuracy and safety of ablation. Pre-operatively obtained CT or MRI scans are used to make 3D reconstructions and these are then registered with the catheter-obtained anatomic models using corresponding points on both maps and best fit surface registration. There are issues with registration, however, in that careful selection of the registration points is essential to increase accuracy.[6,7] In addition the pre-operatively obtained images may have been obtained during different physiological states, such as different rhythms and different filling states, so confounding the registration process. The CT or MRI 3D reconstruction can then be used for similar purposes to the non-fluoroscopic maps themselves, e.g. registration of ablation lesions (Figure 4a and 4b).

Echocardiographic imaging

Transesophageal echocardiography has long been used to assess cardiac anatomy, in certain circumstances better than transthoracic echocardiography is able to. Intracardiac echocardiographic images are taken from within the organ of interest, allowing for image registration without the difficulties of intervening tissue. 3D images can be obtained with all 3 modalities, real-time with transthoracic and transesophageal echocardiography,[8] and at present off-line with intracardiac echocardiography. This allows for real-time and near real-time imaging of chambers and structures and also possibly for lesion assessment.[9] Transesophageal and intracardiac echocardiography are also often used to assist in safe transseptal puncture (Figure 5) and can also be used for localization of intracardiac structures and catheter positioning, for example when ensuring that a catheter is in a pulmonary vein rather than in the left atrial appendage (Figure 6).[10] The CARTO Sound system is an upgrade to the CARTO system which combines this non-fluoroscopic mapping

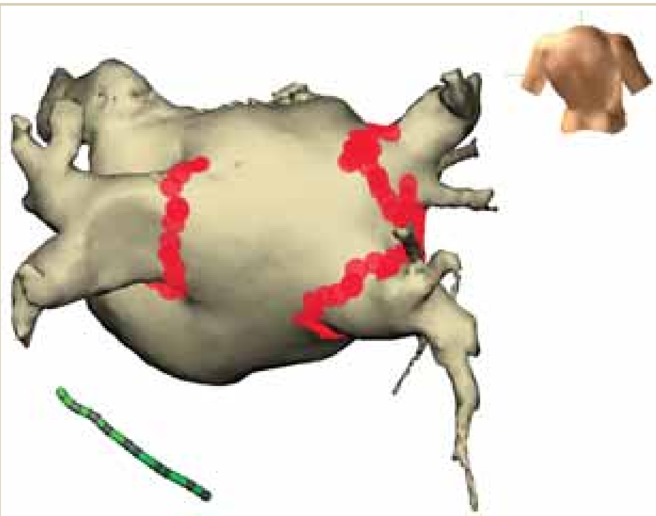

FIGURE 4a: A postero-anterior NavX view of a 3D reconstruction of a left atrium. There is a common left pulmonary vein and two right-sided pulmonary veins with early branches. This image has been fused with the non-fluoroscopic map and has then been used to register the ablation lesions used to isolate these veins.

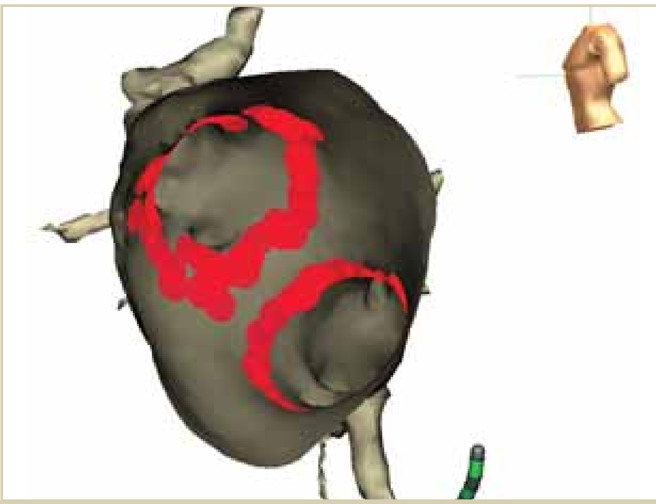

FIGURE 4b: A virtual endoscopic vein derived from the same image as in Figure 4a. The left side of the atrium has been cut away and we are looking at the right superior and inferior pulmonary veins with the lesion sets made around these. Using these images can be very useful in making complete lines of block and successfully isolating the pulmonary veins.

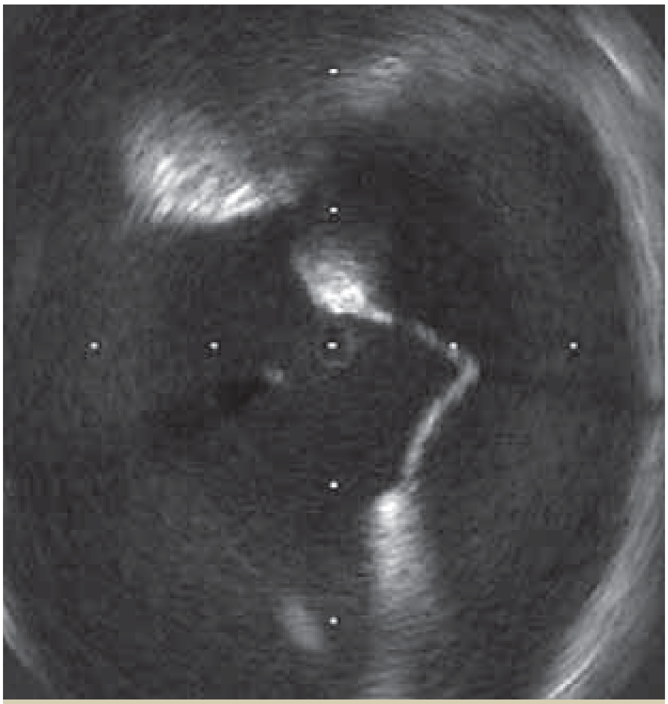

FIGURE 5: An image taken using a rotational intracardiac echo probe (Ultra ICE Catheter, Boston Scientific) showing tenting of the interatrial septum prior to transseptal puncture. Using this, one is absolutely sure about the position of the transseptal needles and can also assess how far the septum tents to prevent inadvertent puncture of the lateral wall. This clearly increases patient safety.

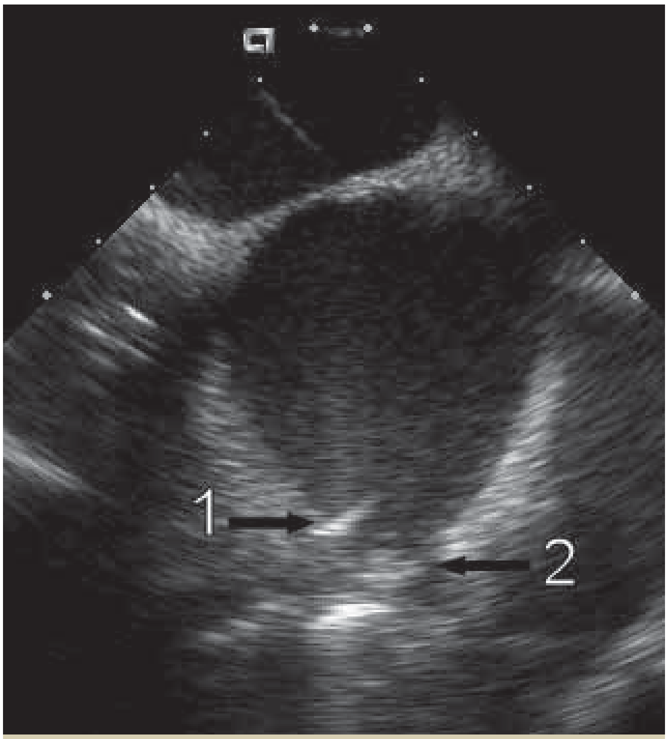

FIGURE 6: An intracardiac echocardiographic image of the left atrium taken from the right atrium using a longitudinal phased array catheter (AcuNav catheter, Siemens). Arrow 1 is pointing at a catheter which is a little deep within the left inferior pulmonary vein. Arrow 2 is pointing at the proximal portion of the left superior pulmonary vein.

system with intracardiac echocardiography in such a way that a 3D image can be built up using multiple sweeps of the chamber of interest. This type of image integration promises much for the future.

Intracardiac MRI

Catheter-based intracardiac MRI may allow placement of special catheters within the heart in a manner analogous to intracardiac echocardiography and allow for assessment of anatomy and lesion formation.[11] This is still very much investigational.

Interventional MRI electrophysiology laboratories

In these investigational electrophysiology laboratories, an MRI replaces the standard C-arm system. Again anatomy, catheter position and lesion formation can be assessed. The challenge at the moment is the construction of specialized catheters needed for electro-physiology which are also MRI compatible.[12]

OTHER ISSUES

One of the issues with any imaging modality is viewing the results of that imaging modality. If one is able to form a 3D picture then some of the benefit is lost if this is then shown on a 2D screen. New innovations are needed in this regard and are currently being assessed. Large rooms have been constructed to view some of these images, allowing the cardiologist to "walk through" the heart and perceive the 3D anatomy.[13]

CHALLENGES

The challenge with all these modalities is to prove that they are beneficial.[14-16] Efficiency and cost-effectiveness need to be shown. Studies evaluating a number of these modalities have sometimes shown conflicting results and this may well depend on what each modality is compared to and where the studies are performed.[6, 17, 18] The initial studies were performed in low complexity substrates and therefore cost-effectiveness proved very difficult to demonstrate. It is also often difficult to show that something is cost-effective in high volume centres where the success rates in complex procedures is already fairly good and the complication rates are low. It is important to remember that with the use of CT scanning there is still considerable radiation exposure, at least to the patient and that catheter-based technology is expensive and invasive. However, the non-radiation based modalities have been associated with significant reduction in radiation exposure for patients and physicians and a tendency to increased success rates and lower complication rates, especially in more complex procedures.

CONCLUSION

I hope to have given the readers an idea of why we need newer imaging modalities and what modalities are available. Decreasing radiation exposure is important and in most cases this has been achieved. We have learnt an enormous amount from viewing 3D anatomy of the heart and have also used these images to plan and execute invasive electrophysiological procedures in a more successful and safer way. The major benefits of newer imaging techniques may be in levelling the playing field so that lower volume centres having to do more complex procedures can have similar success rates to high volume centres.(5)

The future of imaging is in real-time 3D imaging, integrated with robotic catheter navigation systems, allowing for automated mapping and ablation, and perhaps eventually with real-time visualization of the lesions formed, to assist when complete lines of ablation lines have to be drawn.(19)

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