Emerging imaging technologies in ablation

There has been a paradigm shift in electrophysiology because of advances in catheter ablation technology. Advanced imaging techniques are required to evaluate accuracy of catheter tip placement, measure lesion size, and determine location before radiofrequency ablation, improving guidance during technically difficult procedures (eg, transseptal puncture and coronary sinus access), and reducing fluoroscopic exposure to patients and medical personnel. Conventional ablation, such as used for accessory pathways, atrioventricular nodal tachycardia, and typical flutter, has depended on electrophysiologic data alone; however, ablation of new anatomic targets (eg, pulmonary veins) requires electrograms and precise target anatomic information. This is because a misdirected ablation can lead to an unsuccessful procedure or serious complications, including esophageal fistula, pulmonary vein stenosis, or cardiac tamponade from atrial wall perforation. To prevent such mishaps, computed tomography (CT) and magnetic resonance imaging (MRI) have been used before the procedure to define atrial and pulmonary vein anatomy. More recently, fusion imaging has been used. With this modality, MRI and CT images acquired before the procedure and echocardiographic images obtained during the procedure are merged with an electroanatomical map acquired during the procedure.

Preprocedure images do not show anatomic alterations in chamber size and changes in location of pulmonary vein ostia resulting from hemodynamic alterations secondary to changes in heart rate, volume, and blood pressure status; thus, live anatomic imaging during ablation is highly desirable. Live imaging also allows evaluation of anatomy during and following ablation and its correlation with conduction block or lack thereof. Progress has been made in the area of live MRI, live CT, and live 2D and 3D echocardiographic imaging. This article focuses on echocardiography and CT imaging.

Echocardiographic imaging

The most widely used imaging method during ablation is intracardiac echocardiography. Two catheters in clinical use include the Ultra ICE™ (Boston Scientific) and AcuNav™ (Acuson, Siemens).

Ultra ICE is a single-element, mechanical transducer housed in a 9 Fr catheter that provides a 360° radial image at 9-MHz frequency. It does not have Doppler capabilities. As early as 2004, an external motor was used, allowing controlled withdrawal of the catheter at 0.5-mm increments and feeding 2D images at each depth to an external Tom Tec workstation to generate 3D volume data. In a study including 20 patients undergoing caval-tricuspid isthmus ablation for typical atrial flutter, 3D data were acquired, and investigators found 2 types of isthmus anatomy: (1) a prominent Eustachian ridge, which appeared like a curtain arising posterior to the coronary sinus and extending to the anterior wall of the inferior vena cava; and (2) a smooth isthmus with a small inconspicuous vertical Eustachian ridge. Subjects with a prominent Eustachian ridge required far more burns (25 burns) to achieve complete isthmus block compared with those who had a smooth isthmus (8 burns). In addition, unlike 2D images, which show a dense white area reflecting edema in the area of ablation, 3D image reconstruction provided precise visualization of the entire area of ablation, from the tricuspid valve to the inferior vena cava.

The AcuNav catheter is a 10 Fr, 64-element, phased array transducer, which provides a 90° sector image at operating frequencies of 5.5 to 10 MHz. An external motor has also been used with the AcuNav catheter, allowing rotation of the catheter along its axis at 2° to 5° increments and converting the 2D images...
to electrocardiogram- and respiration-gated data on an external Tom Tec workstation. This method was used to obtain data in animal models (5 sheep) and in 6 patients undergoing ablation for atrial fibrillation. All anatomical structures and instruments of interest could be visualized with the catheter tip seated in the mid right atrium, including the ablation catheter in the left atrium, mitral valve, left atrial appendage, all 4 pulmonary veins, thrombus on catheters, right ventricular and left ventricular endocardium, catheter in right ventricle, and interatrial septal anatomy. Acquisition time with this method varies between 1 to 3 minutes based on heart rate. The reconstruction time is 2 to 4 minutes, and this method does not yield live 3D imaging.

Transducer arrays have been mounted on catheters adapted to be used with volumetric scanners that acquire pyramidal volume data from 2 axes perpendicular to the array and B scans parallel to the array. Live 3D data were acquired in an open chest sheep model, whereby the imaging catheter was introduced into the left atrium surgically from the left atrial roof. The catheter was able to visualize pulmonary vein ostia in 3D as well as the mapping catheter introduced from the left ventricular apex, with images mimicking real anatomy and far superior to 2D images used to guide ablation.1

Live intracardiac 3D imaging using an intracardiac catheter is being introduced by General Electric, but live 3D transesophageal echocardiography is the most recent clinically available development.

Another recent development has been the merging of intracardiac echocardiography with electroanatomical mapping and CT imaging using the CartoSound (Biosense Webster) image integration model. The intracardiac catheter is tipped with a biosensor that enables tracking of the catheter in space. The contour of the left atrium and pulmonary veins is traced in each 2D image and assigned a map on a map reader. A 3D shell is then created from the contour. A comprehensive 3D shell of the left atrium and pulmonary veins is made from multiple images. This 3D echo shell is then merged with the CT image.4 The technology is feasible and enables delivery of ablation to precise anatomic targets. The technique may obviate the need for CT images acquired before ablation.

CT imaging

In a CT imaging system configuration, an x-ray projects a fan-shaped beam that is collimated to lie within an X-Y plane of a Cartesian coordinate system; this is generally referred to as the imaging plane.1,5,6 Therefore, during CT imaging, the anatomy of interest passes through this imaging plane and the image data are acquired and reconstructed. Acquisition is typically accomplished by obtaining different views as the x-ray source and detectors rotate around the anatomy or volume. Reconstruction of these data generates a 2D array of quantized gray-scale values or pixels. Pixel values are a measure of the x-ray attenuation in Hounsfield units (HU), where the HU = 1000 - (4µ/µw - 1), with µ being the average linear attenuation coefficient of the volume element represented by the pixel and µw being the

CT imaging and segmentation

Most medical images are made up of an array of small squares or rectangular elements called pixels. Each pixel has an associated image intensity. This provides the coordinate system of the image, and an element in the image can be assessed by its 2D position within this array. A typical CT slice is formed of 512 x 512 pixels, each corresponding to a portion of the cut through the patient and measuring about 0.5 x 0.5 mm2. The matrix and the pixel size are related to the display field of view (FOV). For example, if the FOV is 25 cm, each pixel will be 0.48 mm2 (FOV/matrix size; 25/512). This dimension determines the limiting in-plane spatial resolution of the image. The 2D axial slices are then stacked together to form a 3D volume. Each pixel corresponds to a small volume element, which is called the voxel. The height of the voxel is determined by the slice thickness. Using the above example, if the axial slice thickness is 1.5 mm, the voxel size would be 0.35, determined using the following equation: 0.48 x 0.48 x 1.5 mm3.
linear coefficient of water for the effective energy at the beam exiting the patient. Therefore, water has an HU number of 0 and a region with a CT number of 100. HU has a linear attenuation coefficient that is 1% greater than the linear attenuation coefficient of water.

In the most commonly used ECG-gated helical CT acquisition, the x-ray tube (and detector array) rotates continuously around the patient collecting data, while the patient table (and the patient) is moved at a constant speed through the imaging plane. The helical CT thus collects a continuous sequence of consecutive axial images from a volume of the patient’s anatomy. Faster scanning, as is currently done with 64-slice CT scanners, allows a large volume of data to be collected in short (<10 seconds) periods of time. The factors selected in scanning a patient include slice width, FOV, gantry rotation speed, volume of coverage, and basic contrast injection protocols. Scan time is calculated from the scan volume (total distance traveled by the table) divided by the table speed. The “pitch,” which is defined as ratio of distance the table moves per 360° rotation, is also important. A pitch of 1.0 means the patient table moves a distance of 1 slice. Similarly, a pitch of 0.2 means the gantry rotates 5 times as the table moves a distance equal to the collimator width.

Cardiac motion, due to heartbeat, respiration, and patient movement while lying on the table, can produce artifacts that appear as blurring in the reconstructed image. Such blurring effects may complicate the diagnosis. Employing a short scan time, as can be done with current scanners, may prevent or minimize these artifacts due to the speed of the acquisition. To avoid respiration artifacts, scanning is performed with the patient holding their breath after inspiration or expiration. The acquired data are synchronized with the collection of the ECG (QRS) signal. The ECG signal is recorded in parallel with the CT through a noninvasive monitoring device connected to the patient. The data acquired during consecutive cardiac time intervals can be combined to produce an image of the heart at the same phase of the cardiac cycle. Retrospective gating allows alignment of images during any phase of the cardiac cycle due to the continuous helical acquisition.

Once the image is acquired, it is stored in a proprietary format. The data then can be exported from the scanner. Because images obtained by scanners made by one manufacturer may need to be imported to that of another manufacturer or to a different viewing screen, a medical image standard known as DICOM (Digital Information and Communications in Medicine) has been devised and is widely used. This format allows data to be exchanged between scanners and viewing consoles. The American Radiological convention is to display axial images with the right side of the patient appearing at the left and the posterior side at the bottom of the computer workstation screen.

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In image segmentation, the process of dividing images into different regions to visualize areas of interest is called segmentation. Image segmentation methods can be grouped into thresholding, boundary detection, and region identification.

Thresholding is the simplest but most effective segmentation method. During thresholding, pixels with intensities below a threshold value are assigned one class and the remaining pixels a different class. Regions are then formed by connecting adjacent pixels of the same class; thus, boundary extraction methods use information about intensity differences between adjacent regions to separate the regions from each other. Region identification techniques then form regions by combining pixels of similar properties. The simplest region identifying technique could start with at least 1 seed (a starting point) per region. Neighbors of the seed are visited and the neighbors that satisfy the predicate (a simple predicate compares the intensity values of
the pixel to the average intensity value of the region) are added to the region. Segmentation, as relevant to ablation for atrial fibrillation, for example, can be used to identify the anatomy of the left atrium and its vasculature, allowing it to be viewed separately from the remaining chambers of the heart and the surrounding anatomy, such as the lungs.

Conclusions
The advent of 3D imaging has allowed ablation for complex arrhythmias to become more efficient, safe, and effective. It has also shortened procedure and fluoroscopic time by providing imaging that is more intuitive to the electrophysiologist. Developments in live 3D imaging are ongoing. Live 3D TEE imaging is clinically available, and live 3D intracardiac imaging is on the cusp of availability.

References

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We seek images (eg, ECGs, chest radiographs, MRIs, CT scans, echocardiography) that illustrate common or unusual cardiac conditions. Images should be high-resolution (300 dpi) and saved as commonly used graphic files (eg, JPEG, TIF, BMP); all patient identifiers should be removed. If images require arrows or label placement, two image files should be provided: one with arrows/labels and one without.

Images should be accompanied by a case report that includes pertinent patient history, physical examination findings, diagnostic data, differential diagnosis, management, and outcome. These findings should be organized using the following subheads—Presentation and Evaluation; Diagnosis; and Patient Management and Outcome.

Articles should be no longer than 1,000 words. Documents should be submitted as Microsoft Word files or saved as text files when using another word processing format. Please send document and graphic files as separate attachments; images embedded in Word documents cannot be used.

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