Clinical Perspective

Clinical developments in cardiac activation mapping

Introduction

A number of revolutionary techniques and technologies have been introduced to the clinical electrophysiology laboratory in recent years which have offered new insights into arrhythmia mechanisms and as a result are enhancing strategies for ablating cardiac arrhythmias. They are aimed at improving the resolution, three-dimensional spatial localization, and/or rapidity of acquisition of cardiac activation maps.

Mapping without myocardial contact

The 12 lead surface ECG

The standard 12-lead ECG provides spatial information on regional activity and activation sequences in the heart and has been an enduring clinical tool, and its use for spatial discrimination is still evolving. The rapid expansion of effective ablation therapies in interventional electrophysiology has driven continued refinement of ECG interpretation, an example being algorithms for determining the location of ventricular insertion of accessory pathways causing pre-excitation in the Wolff-Parkinson-White syndrome\[1\]. One such algorithm can localize an accessory pathway to one of 10 sites around the atrioventricular junction with a sensitivity of 90% and a specificity of 99% and has proved particularly useful in localizing pathways in the septum\[1\]. An algorithm has also been developed to localize the onset of endocardial depolarization of ventricular tachycardia in the setting of coronary heart disease. Such an algorithm is limited because it depends on the patient having a single infarct of known location and is therefore applicable to only 59% of tachycardias but has an accuracy of 93%/\[3\].

Body surface mapping

To improve on the spatial resolution of the standard 12-lead ECG, an increased number of skin electrodes have given rise to the technique of body surface mapping of cardiac activation. Recordings made from body surface electrodes reflect electrical activity from the entire heart. The body surface electrogram appearance is a summation of this activity and is dependent on each electrode’s position relative to each of an infinite number of constituent data points within the heart\[3\]. It is possible, using computer processing, to resolve myocardial potentials from the potentials measured at the body surface by use of mathematical equations (based on the inverse solution to Laplace’s equation), but the complexities caused by the signal distortion due to the distance between the source (the epicardium) and the recording electrodes and the heterogeneity of the intervening tissues, limits the clinical use of body surface mapping at the present time.

Percutaneous non-contact endocardial mapping

An alternative application of reconstructing myocardial potentials from data acquired remotely (i.e. without contact with the myocardium) is that of recording cavity potentials from an array of electrodes sitting in the blood pool within the cardiac chamber and not in endocardial contact. In a similar manner to that performed with body surface mapping, inverse-solution methods are applied to these non-contact signals in order to reconstruct endocardial potentials from the raw cavity potentials. The advantages over body surface mapping are that the electrode array is in closer proximity to the source than are body surface electrodes, and the medium (blood) interposed between electrode array and endocardial source is uniform and electrically non-contributory.

A system for clinical non-contact intracardiac mapping has recently been described and validated\[4\] and can rapidly display high-resolution colour maps of endocardial activation in the intact beating heart\[5\] (Fig. 1).

The electrode array is mounted on a 9F catheter and consists of a 7.5 ml balloon around which is woven a braid of 64 insulated 0.003 inch diameter...
Figure 1 A series of three non-contact activation maps of a human left ventricle during ventricular tachycardia resulting from ischaemic heart disease. Activation is shown as a white/coloured dot on a purple background with anatomical labels of the left ventricle shown as follows: Sept — septum, Lat — lateral. Letters a to g run along the location of a diastolic pathway present during ventricular tachycardia. The activation maps show early diastole with endocardial activity beginning in a diastolic pathway (point a), which was the target for catheter ablation of ventricular tachycardia (frame 1), progression of activity through the diastolic pathway from base to apex (point d) (frame 2) followed by activity emerging from the apical end of the diastolic pathway (point g) resulting in systolic activation of the left ventricle.
wires, each with a single break in its insulation, producing 64 non-contact unipolar electrodes. The raw far-field electrographic data are processed by a multi-channel amplifier and computer workstation.

The system is applied in three steps:

1. Cardiac chamber geometry is established
2. Site(s) critical for maintenance of reentry circuit(s) are identified
3. Ablation catheter is navigated to critical site(s)

A catheter locator system is central to steps 1 and 3 while the inverse solution for reconstructing endocardial electrograms is central to step 2. A ‘locator’ signal emitted from the catheter electrode allows its position to be determined relative to the electrode array. It can be used to construct the three-dimensional computer model of the endocardium (virtual endocardium) by moving the conventional catheter around the cardiac chamber, thus building up a series of co-ordinates for the endocardium, and generating a contoured model of its geometry. The catheter’s location may then be displayed on this virtual endocardium. Reconstructed electrograms are then superimposed onto the virtual endocardium to produce isopotential maps.

Electrogram reconstruction was validated by comparing the morphology and timing of reconstructed electrograms with contact electrograms from the same endocardial location (as indicated by the catheter location system)[4]. The accuracy of electrogram reconstruction is good, but decreases with increasing distance between the electrode array and the endocardium and this becomes significant for distances >34 mm.

The use of the non-contact mapping system in mapping and ablation of ventricular tachycardia has been investigated in 24 patients with well-tolerated ventricular tachycardia. The non-contact system was used to map 81 ventricular tachycardias and demonstrated an endocardial site of origin of systolic ventricular activation (exit site) in 99% of these. Portions of the diastolic component of the reentry pattern. Furthermore, the exact replacement of an ablation catheter onto a location of interest previously identified with sequential mapping is difficult because of the limited resolution of fluoroscopy. Mapping during sinus rhythm has been attempted in order to identify regions critical for the maintenance of ventricular tachycardia while avoiding the need for prolonged mapping during arrhythmia but such techniques have low sensitivity and specificity[12].

Mapping with myocardial contact

Conventional catheter mapping

For optimal electrical signal recording and mapping, conventional technology has required that recordings are made from close proximity to, or contact with, the endocardium. Conventional mapping is achieved by sequential acquisition of a series of endocardial electrogram recordings from a roving catheter mounted with a small number of electrodes[10]. There are a number of limitations with this approach. It is time consuming and therefore as few as 10% of patients with ventricular tachycardia in the setting of structural heart disease may be suitable for such mapping and catheter ablation[11] principally because of haemodynamic intolerance. In addition, the acquisition of sequential data points does not allow mapping of non-sustained arrhythmias or arrhythmias with beat-to-beat variations in timing or activation pattern.

Mapping at surgery

More detailed simultaneous epicardial and endocardial activation mapping has been performed during surgery by applying multiple electrodes to the
epicardial surface, or electrodes mounted on a balloon introduced through the mitral valve to the left ventricular endocardium\[13\]. This has allowed the mapping of patients with multiple, complex and non-sustained tachycardias. It has also been possible to use these data to construct three-dimensional endocardial maps of ventricular tachycardia\[14\]. Surgical mapping does have limitations; ventricular tachycardia may be non-inducible because of anaesthesia or surgical manipulation of the heart\[10,15\] and mapping under anaesthetic with an open chest and possible ventriculotomy has an associated morbidity and mortality\[16\]. It is now generally reserved for patients already undergoing cardiac surgery for other reasons such as coronary artery bypass grafting.

**Basket catheter mapping**

Simultaneous mapping of multiple points has been performed using endocardial basket arrays which can be deployed percutaneously (Fig. 2). Current designs of basket arrays consist of a series of equally spaced electrode pairs mounted on 5 to 8 flexible splines which can be straightened and advanced from a percutaneous sheath into the cardiac chamber of interest so that the splines deploy and are apposed against the endocardium. Resolution is limited to the proportion of electrodes that are in contact with the endocardium and by unequal deployment and spacing of the splines, especially if the geometry is distorted, for example by left ventricular aneurysm. Nevertheless, successful ablation of ventricular tachycardia in humans guided by basket mapping has been described\[17\]. Basket catheters have also been deployed to assess right atrial activation patterns around the crista terminalis before and after ablation, although the baskets were withdrawn prior to the ablation procedures\[18\]. A basket catheter has also been used to characterize atrial fibrillation and demonstrated organization of atrial electrograms in basket electrodes prior to atrial fibrillation termination\[19\]. Although the spatial resolution requires interpolation of data, current designs of basket mapping systems are able to display animated activation maps and also have catheter location systems which allow the operator to guide an ablation catheter to a particular electrode on the basket.

**Electroanatomical mapping**

A system for three-dimensional reconstruction of the location of sequentially acquired contact catheter electrographic data has been described and validated\[20\]. The technology is based on a catheter location system which determines a mapping catheter’s position and attitude within an ultra low magnetic field emitted from radiators positioned under the operating table. An operator sequentially acquires contact electrograms around a cardiac chamber using a catheter containing a magnetic sensor and the system determines the positions at which these electrograms have been sampled. A three-dimensional computer model of the cardiac chamber (or chambers) is then constructed from these points and the electrogram activation timings are superimposed onto this model to display isochronal maps (Fig. 3).
Figure 3  Anterior (frame 1) and posterior (frame 2) views of an isochronal map of the right atrium produced by an electroanatomical mapping system. The coronary sinus (CS), tricuspid annulus (TA), superior (SVC) and inferior vena cava (IVC) have been marked. Earliest activation is shown at the CS os as red with latest activation (blue/purple) in the lateral right atrium. This isochronal map would be compatible with activation of the right atrium during coronary sinus pacing or from a posteroseptal accessory pathway during orthodromic atrioventricular tachycardia.
In order for the system to determine changes in the catheter’s position within the heart, the position of the heart must be fixed relative to the field emitters. The mapping catheter’s location is gated to the ECG to adjust for changes in the cardiac position due to myocardial motion, and the mapping catheter location is determined relative to a stable reference catheter within the heart which accommodates for changes in cardiac position due to respiratory movement.

Validation data in both in-vitro and in-vivo studies have demonstrated an accuracy in catheter location to <1 mm\[^{20}\]. The system has been used to map activation of the right atrium during sinus rhythm and typical atrioventricular-nodal reentrant tachycardia, to guide ablation of the Wolf–Parkinson–White syndrome by mapping the mitral annulus and by identifying an area corresponding with the earliest ventricular activation\[^{21}\], and to guide ablation of atrial flutter\[^{22}\] and focal atrial tachycardias\[^{23}\].

Electroanatomical mapping has been reported as successfully mapping and guiding ablation in two cases of focal\[^{24}\] and one case of scar-related macro-reentrant ventricular tachycardia\[^{25}\]. It has also been used to map haemodynamically unstable ventricular tachycardia during sinus rhythm in order to identify channels of conducting tissue in ventricular scar, thus identifying a region with the potential to act as a diastolic pathway during reentrant ventricular tachycardia. Haemodynamically unstable ventricular tachycardia has also been ablated by using the electroanatomical mapping system to determine the extent of scar in the ventricle and then using the system to guide the creation of multiple linear radiofrequency lesions to isolate the scar.

Catheter ablation to cure atrial fibrillation is undergoing progressive refinement. The catheter maze procedure is used to compartmentalize the atrial myocardium by the creation of lines of block connecting some anatomical atrial structures. Creation of these lesions must be guided by precise positioning of the ablation catheter. Electroanatomical mapping has been used to guide such anatomical ablation of atrial fibrillation in humans\[^{26}\]. Creation of linear lesions in this way is dependent on the system’s ability to precisely locate each site of radiofrequency energy delivery, thus increasing the likelihood that a confluent line of lesions is produced.

Although this development is a significant advance in mapping technology, creation of an activation map requires that the rhythm is regular, and resolution is limited by the time available to acquire sequential data points. Its use therefore remains restricted in cases of non-sustained or haemodynamically unstable arrhythmias except for acquiring relevant data during sinus rhythm. Despite these limitations, electroanatomical mapping significantly improves catheter navigation and three-dimensional display of arrhythmia mechanisms with the advantage of reducing X-ray exposure to the patient and the operator.

Summary

The development of new mapping systems are beginning to overcome some of the limitations of conventional techniques (Table 1). Most of these systems continue to undergo development and none of them completely encompass all the requirements for an ideal mapping system. However, ablation of complex arrhythmias like ventricular tachycardia and atrial fibrillation is becoming increasingly feasible with the use of 3 dimensional electrophysiological and anatomical maps.

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References


