Image fusion and catheter robotics for EP procedures

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IMAGE FUSION AND CATHETER ROBOTICS FOR ELECTROPHYSIOLOGY PROCEDURES

Mark O'Neill
Imperial College London & Imperial College London Healthcare NHS Trust, London, UK

Atrial fibrillation (AF) is a supraventricular tachyarrhythmia characterized by uncoordinated atrial activation with associated deterioration of atrial mechanical function. It is the most common cardiac arrhythmia, becomes more prevalent with age, and is associated with an increased long-term risk of stroke, heart failure and all-cause mortality. It is likely that most AF occurs primarily in the context of an interplay between left atrial electrical and mechanical dysfunction and later becomes self-perpetuating by promoting further electromechanical change during ongoing fibrillation[1, 2].

It is widely accepted that the pulmonary and thoracic veins are the sites of origin of ectopic depolarisations initiating AF however the mechanisms which act to sustain AF are less well understood but may include multiple wavelet reentry, discrete localised reentry and rotors around a fixed or functional pivot point. Postulated electrophysiological correlates of these mechanisms which can be objectively demonstrated during AF include areas of high dominant frequency detected by spectral analysis, and local high frequency atrial sites in which most of the arrhythmia cycle length can be displayed across multipolar contact electrograms with centrifugal activation from that site. However, mapping of the arrhythmic substrate during AF is fraught with potential sources of error, including the transient nature of fractionation, the dependence of fractionation on atrial cycle length, and the need for at least 5s of consistent electrical data to characterise a fractionated atrial electrogram.

Catheter-delivered therapies for AF are dependent on real time manual integration of this complex electrical information with three-dimensional spatial information. Once achieved, effective and contiguous radiofrequency lesions must be safely deployed in the atria of the spontaneously breathing, sedated patient, while avoiding collateral damage to critical intra-and extra-cardiac structures. For simple, well characterised arrhythmias with a fixed anatomical circuit, for example atrioventricular re-entrant tachycardia, the electrical timing information is paramount while the degree of structural resolution required to aid interpretation is minimal. For complex arrhythmias like AF or ventricular tachycardia, it has been shown that the anatomical context of the electrogram recordings is a crucial guide to therapeutic success by means of catheter ablation although our understanding of this electroanatomic interplay is rudimentary at best and based on the painstaking description of electrical phenomenology in small patient groups[3].

Electroanatomic mapping can localize a given electrode in 3D space and thereby enable the construction of a representation of atrial anatomy while simultaneously gathering activation timing and voltage amplitude data. Magnetic resonance or tomographic cardiac images acquired before the ablation procedure give detailed anatomic, and more recently functional, information that can be useful to plan the procedure. These images can be imported or "merged" into the electroanatomic platform and integrated with the mapping-acquired anatomy to aid catheter manipulation during the ablation procedure[4]. Such techniques are now widely available, can reduce radiation exposure and may improve procedural outcomes.

More recently, remote catheter navigation systems have been developed with the purpose of improving catheter tip navigation and consequently, stability and effective, transmural lesion delivery. There are date in support of a role for both the robotic Hansen system[5] and the magnetic Niobe system[6] in facilitating catheter ablation procedures, thereby potentially reducing dependence on a high degree of manual dexterity to achieve an acceptable clinical outcome.

At a fundamental level however, the limited resolution of current mapping technologies is an obstacle to a more complete understanding of the underlying mechanisms in complex arrhythmias. Although great progress has been made in real-time tracking of manual and assisted catheter manipulation within reconstructed and registered anatomies, interpretation of the significance of recorded activity requires greater development, with an emphasis on online global substrate mapping during AF. With greatly improved signal interpretation methodologies, it should be possible to optimize the use of the rapidly developing imaging and navigation modalities. When used appropriately together in real time, these three facets of technology relevant to electrophysiologists – signal analysis, imaging (both qualitative and functional) and catheter manipulation - may facilitate the development and exploitation of an AF signature in an individual patient, allow custom selection of ablation targets and tools to optimize the patient's procedural and clinical outcome.

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