Combined MR-Xray Suites: An essential pre-requisite for MR-EP?

Over the last two decades, advances in the understanding of arrhythmia mechanism and catheter design have resulted in a high degree of success for the cure of regular narrow complex tachycardias. Extension of the principles and techniques of conventional electrophysiology (EP) to more complex arrhythmias such as atrial fibrillation (AF), atypical left atrial flutters and scar-related ventricular tachycardia have led to significant advances in the management of these problems, but with more modest clinical success. This is largely related to the technical difficulties of catheter navigation and manipulation within the heart using x-ray fluoroscopy alone, together with the electrophysiological complexity of both the arrhythmia and its anatomical substrate.

Whilst catheter navigation has been greatly facilitated by the development of non-fluoroscopic electroanatomic mapping systems, geometries constructed by conventional electroanatomic mapping suffer inherent limitations, which, if overcome, might translate into improved catheter navigation and lesion delivery. Magnetic resonance-guided EP (MR-EP) offers several potential advantages over x-ray fluoroscopy and conventional electroanatomic mapping systems. It provides rapid, high resolution, 3D visualisation of the true anatomy and endocardial surface of the cardiac chambers with unrivalled soft tissue contrast, the potential to visualise ablation lesions and acute complications with high spatial resolution and raises the possibility of eliminating patient and physician exposure to ionising radiation.

Whilst previous studies have demonstrated the feasibility of MR-EP using both passively and actively tracked MR-compatible catheters, translation into human studies has been limited and none of these studies has demonstrated all of the components of an MR-EP system to rival conventional electroanatomic mapping and ablation. We have recently shown the pre-clinical feasibility of an actively-tracked fully MR-guided system with activation mapping before and after irrigated radiofrequency (RF) ablation, as a prelude to a planned human study.

Using active catheter tracking, MR catheters were easily positioned in the coronary sinus and Right Atrium (RA) in all animals, without the need for fluoroscopy. Thereafter, both catheters, with minimal MR interference, could record high-fidelity electrograms and atrial capture with RA and coronary sinus pacing was seen in all animals. As the RA mapping catheter was moved around the chamber during active tracking, its position was updated on the 3D RA shell and the three-view 3D b-SSFP multi-planar reformat automatically updated according to the catheter location. Irrigated RF ablation was successfully performed from the SVC to IVC in all animals. The tracked catheter position was verified by real-time imaging prior to each ablation delivery

This study was designed to show the feasibility and safety of a fully MR-guided EP system, which would be suitable for use in human studies. All of the steps necessary for RA ablation were demonstrated: real-time catheter navigation, pacing, irrigated

linear RF ablation and pre- and post-ablation imaging and activation mapping. Successful RF ablation was demonstrated by a change in activation pattern following ablation and transmural injury seen at microscopic examination. There were no complications in any of the animals.

Previous studies investigating the potential of MR-EP have focused on the feasibility of performing EP studies and limited RF ablation in an MR environment. However, the many technical challenges of performing MR-EP procedures explains why, despite the first description of MR-EP in 2000, its uptake in human use has been limited to either EP studies alone (without ablation) or to an isolated case report of cavotricuspid isthmus ablation.

One of the principle limitations to clinical use of MR in interventional EP remains the availability of clinical-grade MR-compatible catheters. Currently available MR-compatible catheters rely on either passive or active tracking for visualisation. Passive tracking (used in the two aforementioned human studies uses magnetic susceptibility artifacts or signal voids created by the catheter tip, whilst active tracking (used in this study) requires the creation of a signal that is actively detected by a catheter tip RF coil, in order to identify its location. However, the coil needs to be connected to the scanner with a conductive wire and rapidly changing magnetic and electrical fields can result in substantial local heating, which would be unsafe for clinical use. The custom-designed transformer-based transmission lines used in the catheter in our study have been previously shown to undergo negligible RF- and pacing-induced resistive heating in safety testing.

Furthermore, additional wires equipped with inductive and resonant element allow the recording of high-fidelity intracardiac electrograms. No MR imaging was performed during recording of intracardiac electrograms in our study. However, MR-induced artefacts on electrograms can be suppressed efficiently by filtering. Pacing was also successfully performed via these wires with a standard clinical stimulator.

MR-EP has the potential to visualise the formation of ablation lesions in real-time and to assess gaps in and transmurality of ablation lesions. Using T2W images lesion assessment by MR can also be carried out.

MR-guided electroanatomical mapping and ablation using active catheter tracking is safe and feasible and the MR-EP setup provides an efficient workflow. Catheters show good localisation accuracy and intra-cardiac signal quality in vivo and allow for pacing and ablation using standard RF equipment. Combined with intraprocedural lesion imaging MR-EP has the potential to significantly improve the way current ablation procedures are performed.

It is important however to have the back up of an X-ray cardiac catheterisation laboratory in carrying out these procedures as it may not be possible to carryout to complete procedure under MRI guidance. For example in the recently published series of 15 patient who underwent the MRI guided ablation of atrial flutter only one patient was able to have the procedure under MRI guidance only. When we moved

to the more complicated but much more important cases of ablation of atrial fibrillation under MR guidance then it is going to be essential for the first few years to have the back up of completing the procedures under X-ray fluoroscopy.

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