Setting Up an MR Suite for Electrophysiology

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Introduction

Cardiac arrhythmias are common, affecting 3-5 % of the over 40s, which is expected to grow due to ageing population [1]. Cardiac arrhythmias cause considerable morbidity and significant mortality as well as considerable anxiety in patients and their relatives. Early and accurate diagnosis is essential for the selection of the appropriate treatment. Over the last decades the application of ablation therapy has shown as a successful alternative over drug treatment [2-5]. For this, the arrhythmogenic substrate is elucidated by measuring the electrophysiological (EP) signal inside the heart. It is often possible to completely cure the condition by either burning the endocardial surface where the abnormal electrical activity is originating or to block the propagation of the abnormal electrical activity. This procedure, which is called radio-frequency (RF) ablation, deposits RF energy via specially adapted catheters. Currently, X-ray fluoroscopy is the standard technique used for image guidance. However, this imaging modality offers no 3D information and soft tissue contrast, making catheter navigation within the heart difficult. In addition, due to the electrophysiological complexity of the arrhythmia and its anatomical substrate the procedure normally takes several hours with X-ray fluoroscopy and requires skilled operators. Recently, electro-anatomical mapping systems (Biosense Webster Carto, California, USA, and St Jude Medical ESI, Minnesota USA) generate static anatomical maps by tracking the electrical catheters or by importing a static 3D image dataset (CT or MRI). However, there is a degree of inaccuracy in the registration of the MR or CT derived and mapping catheter-derived surfaces.

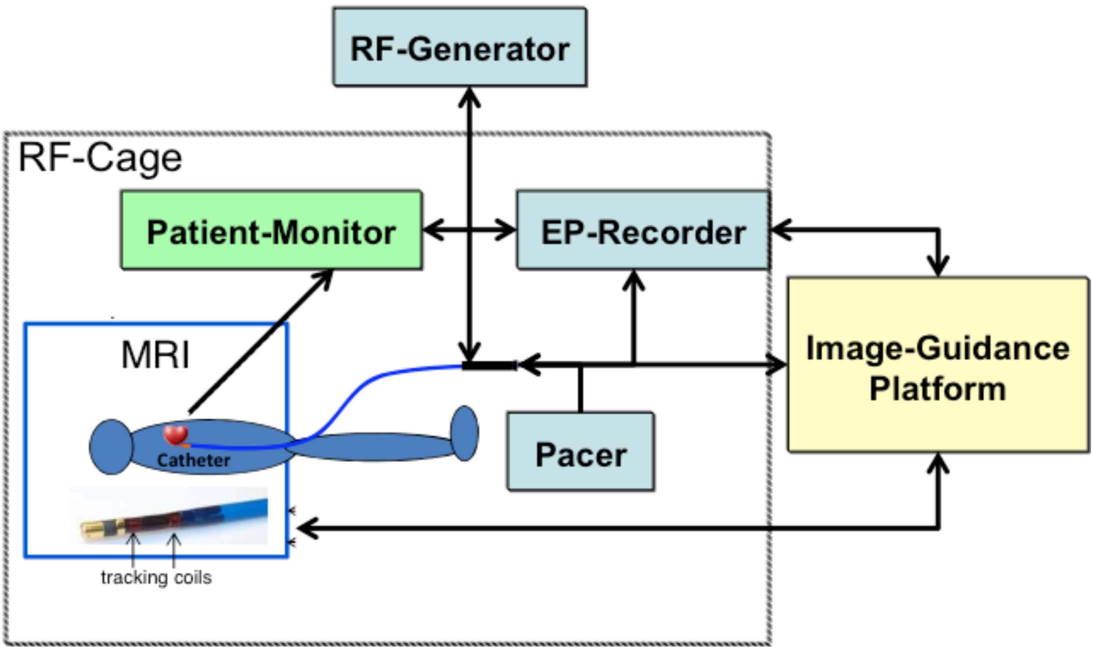

Figure 1: Components of an MR-guided EP-Platform

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MR-guided EP

Magnetic resonance-guided EP (MR-guided EP) offers several potential advantages over x-ray fluoroscopy and electro anatomic mapping systems. It provides high-resolution 3D visualisation of the true anatomy with unrivalled soft tissue contrast, the real-time guidance of catheter devices and the potential to visualize ablation lesions and acute complications while eliminating patient and physician exposure to ionizing radiation. Recently a number of groups have demonstrated the feasibility MR-guided EP procedures using passively and actively tracked catheters [6-14]. MR-guidance has been used both for obtaining intra-cardiac EEG signal in a mapping procedure and to perform rf-ablation inside the MR-scanner. Moreover, it has been shown that MRI can be used for the assessment of rf-ablation lesions [15-20]. In order to perform a fully MR-guided EP-procedure (EP-mapping and RF-ablation) a number of components have to be integrated into a MR-EP suite. Figure 1 shows the components and their interaction. The MR scanner provides anatomical information, allows for real-time tracking of MR-compatible EP-catheter devices and can be used for the assessment of ablation procedure. An MR-compatible patient monitoring system is used to obtain vital signs such as filtered ECG signals during MR-scanning. An MR-compatible EP recording system allows for obtaining intracardiac electrograms during MR-scanning. An RF generator is connected to MR-compatible EP-catheter devices for ablation therapy. In the following the different components will be described in more detail:

1. **MR-compatible catheter devices and safe tracking technology.**
   EP procedures require highly specialized catheters with a range of functions to perform EP-mapping and ablation procedures while tracking the catheter position. EP catheters require electrodes for recording of the intra cardiac signal with an amplitude of approx.10mV with maximal frequency of approx. 1 kHz. Additionally, intracardiac pacing is performed with these electrodes using currents of 10mA and a maximal frequency of 100 kHz. In conventional EP catheters, these signals are transmitted by copper cables, which are impermissible in MR due to potential RF heating [21, 22]. Highly resistive (HR) wires with a resistance in the order of several kΩ have been shown to reduce heating effectively while transmitting electrical signal for EP-recording and pacing [23].
   Another important requirement is to provide the cardiologist with images showing the myocardial tissue and the position and shape of the catheter devices. However, device visualization with two-dimensional MRI is complicated by the fact that for a tomographic imaging modality the device has to stay within the imaging slice. Therefore fast catheter-tracking techniques are highly desirable, i.e. to track the MR-safe catheter devices within the MR-scanner. A variety of techniques have been proposed for these purposes, many of which incorporate a receive micro-coil in the catheter tip and localizing this coil by obtaining projections [24]. This allows the rapid tracking of the catheter tip in three-dimensional space within the coordinate system of MR-images and thus being inherently registered. In order to minimize RF heating associated with the active tracking components, the micro coil can be connected to a transformer-based cable suppressing the common mode RF currents [23, 25].

2. **MR-compatible Patient Monitoring.**
   An MR-compatible patient monitor is required to obtain vital signs of the patients during the intervention, such as ECG, SpO2 and respiration. The filtered surface ECG can also be used for triggering of the MR-acquisition and providing a reference EP-recording. For this, ECG transmission should be established from the patient monitoring system to both the EP recording system and the MR scanner. This allowed for patient monitoring, activation mapping, and MR-triggering using a single set of ECG electrodes.

3. **EP-recorder, Pacer and RF generator**
   The EP-catheter devices are connected to an EP recorder to receive the intracardiac electrograms. MR-scanning results in artifacts in the electrograms due to the application of rf-pulses and gradients requiring dedicated filter to recover the signal. In addition, ECG-signal obtained from surface electrodes can be used for reference, i.e. the timing of the intracardiac electrograms can be related from a first catheter to those of a second catheter or to the surface ECG. After the time delay has been determined for a specific catheter position, this information has to be related to the anatomy as a mapping point. For this, the point is displayed on the image guidance platform. While this is repeated for a large number of different catheter positions, the image guidance platform also generates a color-coded representation of all mapping points called time-map. Sometimes activation data needs to be acquired under pacing, e.g. by using and additional pacing catheter in the coronary sinus, which is connected to a pacer. Finally, an RF-generator needs to be connected to the EP-catheter to perform RF-ablation for treatment.

4. **Image-Guidance Platform**
   This builds the core component of the MR-EP suite to integrate the different information, i.e. MR-images, catheter position and intracardiac electrograms or time delays. In particular real-time visualization of the catheter position on a 3D roadmap is required to guide the procedure. This can either be done on reformatted MR-images or endocardial surface extracted from a 3D MR-dataset [26]. Sometimes the cardiac anatomy is dynamically changing due to respiratory motion. Therefore, either real-time MRI or a motion compensated roadmap needs to be used [27, 28].
   For the ablation therapy the position of the catheter device and the atrial wall thickness is of importance to create a transmural lesion while avoiding perforation by applying to high RF-energy. Local MR imaging can be used to confirming the catheter position and determining the wall thickness before RF-ablation. In addition, non-invasive MR-techniques can be used to quantify the size and shape of the ablation lesion. These techniques are either based on delayed enhancement of lesions using a contrast agent [15,16] or using T2-weighted imaging for imaging of edema [17,29]. Furthermore, the three-dimensional visualization of the lesions and edema pattern [30] is of great importance to provide the interventionist with location of potential gaps.

Conclusion

MR-compatible catheter technologies, advances in cardiac MRI and image integration allow the guidance of electrophysiology procedures. Such an MR-suite will likely improve the identification of the arrhythmogenic substrate and facilitate complex arrhythmia procedures.

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