MR-Guided Electrophysiology System for Activation and Pace Mapping in Left Ventricle

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Introduction. Combination of electrical mapping and morphological characterization of substrate are both crucial for the success of ablative electrophysiological (EP) procedures in patients with ventricular tachycardia (VT). One of the most common substrates of monomorphic VT is the presence of reentry pathways associated with post-myocardial infarction (MI) scars. In the electrophysiology domain this scar is identified as low voltage regions on ventricular voltage map with diminished excitability - manifested by high or unattainable pacing threshold. In the MR domain, scars may be visualized with the use of delayed enhancement techniques (DE-MRI). In recent studies, EP information has been compared with pre-acquired MR images to determine the relation between the two measurements; however, that approach is sensitive to registration errors and changes in anatomical conditions. Here, we present an MR-compatible EP system for real-time MR imaging able to directly locate and characterize electrical properties of potential arrhythmogenic regions in the left ventricle (LV) identified by MR. Similar designs have been presented in recent publications, although with different scopes and features [1, 2, 3, 4].

Methods. We performed all experiments on a 1.5T GE Signa system (GE Healthcare, Milwaukee, WI, USA); images were acquired using 5-inch surface coil. EP measurements were recorded using CardioLab 7000 Electrophysiology unit (GE Healthcare, Milwaukee, WI). Two MR-compatible catheters were used: (1) 2-electrode 1-tracking coil catheter** and (2) 2-electrode 5-tracking coils catheter. X-ray fluoroscopy using an X-ray C-arm, (OEC 9800, GE Healthcare, Salt Lake City, Utah), was used only for initial catheter placement; all subsequent manipulations were performed using active MR-tracking at 10fps [5]. Pacing was performed with a temporary stimulator (EP-4, St. Jude Medical, Minnetonka, MN) located outside the rf-shielded room. Capturing (successful contraction of the myocardium in response to stimulation), was validated on both Cardiolab and the scanner's ECG monitor. The interconnectivity apparatus for signal transmission and filtering was built in house. To date, procedures have been performed on 5 pigs.

Results. Intracardiac electrogram (IEG) signals were reliably recorded while tracking was active and inactive. Pacing was also possible while tracking. In Fig. 1, pig sinus rhythm was recorded at a 600 ms cycle length or 100 beats-per-minute (BPM). Successful pacing was achieved during MR tracking. Specifically, Fig. 1 shows pacing at 5mA from catheter #1 and successful myocardium capturing recorded with catheter #2 at cycle lengths of 550ms (110BPM) and 500ms (120BPM). In Fig. 2, approximate long-axis and short-axis views are shown of the ventricle with the two catheters positioned in the LV. The colored symbols represent the tracking coils as displayed on the tracking tool.

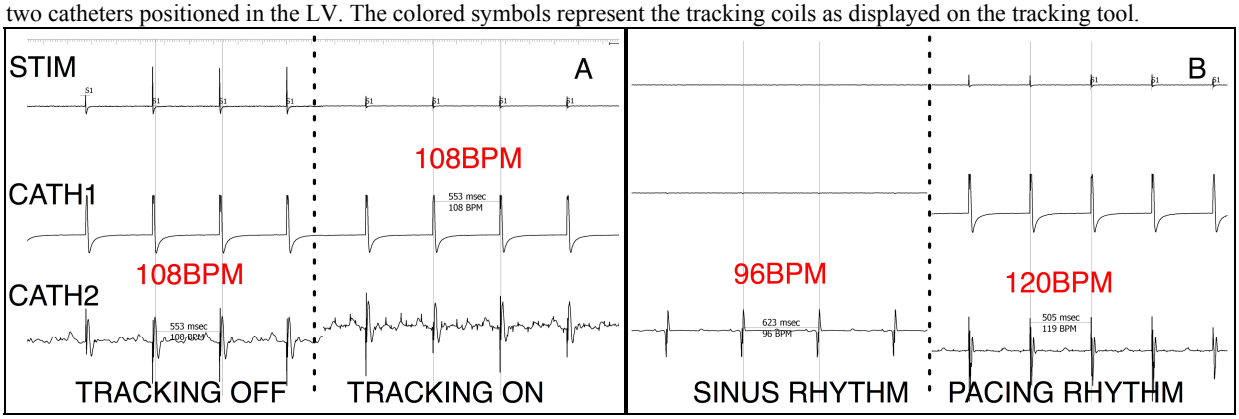

Figure 1. Bipolar recordings are shown for catheter #1 (pacing catheter), catheter #2 (sensing) and stimulator (STIM). (A) Intracardiac signals are shown while pacing with active catheter tracking off and tracking on. (B)The successful myocardial capturing is shown with the resulting override of the sinus rhythm by the pacing rhythm at a cycle length of 500ms (120BPM).

Discussion. The RF filters used in the connection circuit were able to isolate the rf-shielded room from the operator console: MR images and catheter tracking were not corrupted by the EP system; similarly, IEGs were only minimally impacted by tracking operations. Our system showed the ability to track multiple devices, which is extremely important for replicating the clinical EP procedure. Additionally, pacing was followed by successful myocardium capturing and was easily confirmed by the change of heart rate, which indicates sinus rhythm override. Ultimately, the significant advantage of our system lies in the fact that it allows for multiple devices tracking, and the ability to pace and record signals in multiple locations simultaneously. This last point is significant as it provides an essential tool for the electro-physiologist to localize the source of the arrhythmia, potentially measuring local conduction velocities at different pacing frequencies. By doing so, our system proves to be a powerful tool for relating electrical properties to MRI-based scar-region characterization, which is the objective for our future work.

Conclusions. In conclusion, we presented an MR-compatible EP system for real-time MR imaging able to perform localized pacing and mapping to directly locate and characterize potential arrhythmogenic regions in the left ventricle (LV).

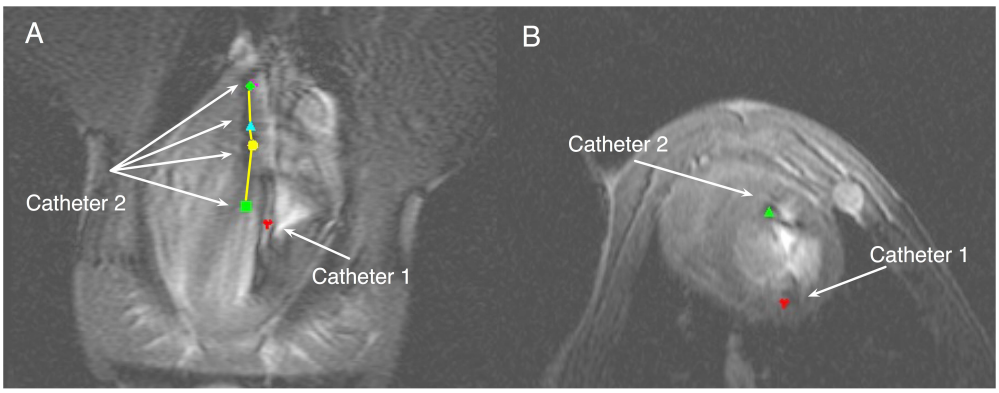

Figure 2. Approximate (A) long and (B) short-axis views of the LV are shown. The colored symbols represent the tracking coils for both catheters as shown by the tracking tool. Catheter #1 (pacing) had a single tracking coil located at the tip (red symbol) and the catheter #2 had 5 coils with the green square representing the tip. For clarity, in B only one coil is shown for the recording catheter.

References: [1] CIR 2008 vol.118 (8) pp. 853-62; [2] CIR 2008 vol.118 (3) pp. 223; [3] CIR ARR EP 2009 [4] ISMRM 2005 #272 [5] MRM 1993 vol.29 (3) pp. 411-5;
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