MRI-compatible Voltage-based Electro-Anatomic Mapping System for Cardiac Electrophysiological Interventions

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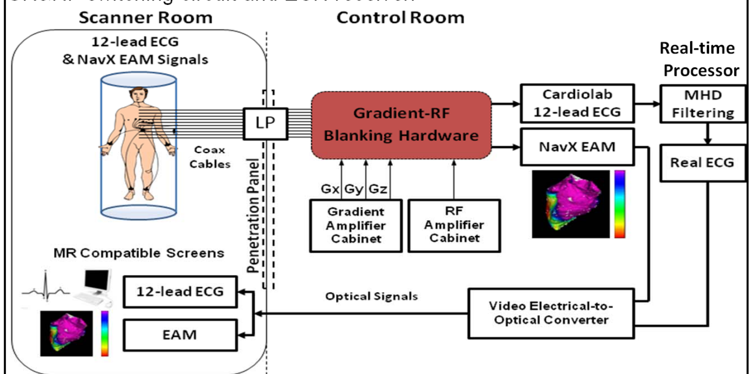
Introduction: Ventricular Tachycardia and Atrial Fibrillation are commonly treated with Electro-Physiology (EP) ablation procedures. Visualization of luminal & vessel-wall anatomy, and identification of edema and scar tissue are essential to EP, and could be enhanced by pre-operative and intra-operative MRI. Until MR compatible EP devices are widely available, however, there will be a need to perform EP procedures partially inside MR magnets (i.e. imaging), and partially outside the magnet (e.g. ablation). Intra-cardiac navigation and Electro-Anatomic Mapping (EAM) are currently accomplished by either magnetic- or voltage-based technologies, neither of which are fully compatible with MRI. Consequently, MRI tracking methods have been developed for use inside MR magnets [1-2]. Multiple device tracking methods, however, complicate EP procedures and a single approach that works both in and outside the magnet is desirable. It was hypothesized that an MR-compatible St. Jude Medical (SJM) EnSite NavX (ESN) system, based on voltage tracking, could provide catheter tracking and registration-free EAM in and outside MRI [3]. ENS localizes catheters by placing 5.8/8kHz voltages between 3 pairs of surface patches and measuring the induced voltages at electrodes on the catheter [4]. The catheter electrodes also measure intra-cardiac ECGs. A challenge for intra-MRI use of ESN is interference induced by MR gradient ramps. In addition, there is a need to minimize MR Image Quality (IQ) reduction and patient-skin heating.

Fig.1: MRI-compatible ESN System: Inside the scanner room are modified surface patches, RF ferrites and low-pass filters. Outside the room are GR&RF switching circuit and ESN receiver.



Materials and Methods: Fig. 1 shows the MRI-compatible ESN setup. Inside the MRI room, modified ESN surface-patches are attached to the chest. Ferrites on the coaxial ESN leads (Fig.2), and RF filters at the penetration panel minimize IQ reduction and patient-skin heating. An electronic Gradient-RF blanking circuit (Fig.3), disconnects the ESN leads from the ESN receiver when MRI gradient-ramps-&-radio-frequency-pulse (GR&RF) transmissions are detected, blocking GR&RF noise from reaching and saturating the ESN receivers [5]. Intra-MRI ESN was validated using a cardiac phantom and three swine models on a GE 1.5T MRI. Varying GRE, SSFP & FSE imaging parameters and slice orientations were tested, using two MRI-compatible deflectable EP catheter prototypes made by SJM (Fig. 4).

Fig.2: ESN cables with ferrites placed at positions where RF amplitude is maximal.

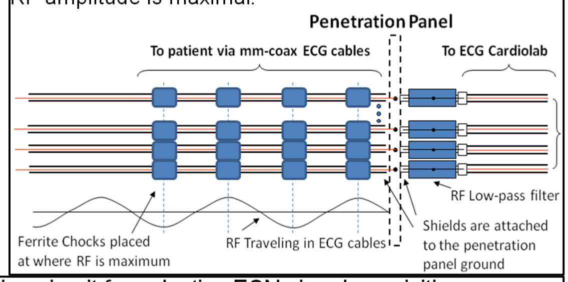
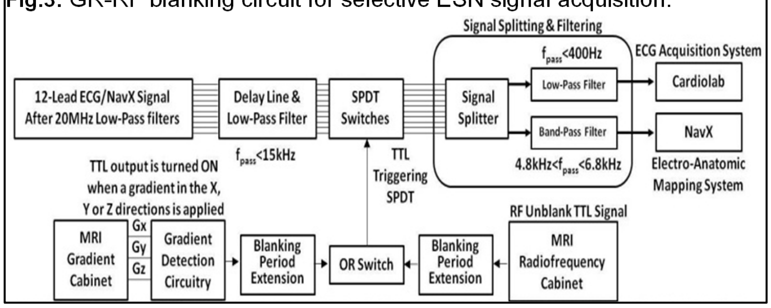


Fig.3: GR-RF blanking circuit for selective ESN signal acquisition.



Results: Simultaneous ESN and MR tracking were performed in the phantom with the dual ESN and MR-tracked catheter (Fig. 4a), showing consistency in the 2 tracking methods (Fig. 5). EAM was performed using ESN in 3 pigs with concurrent MRI imaging and tracking. Tracking of 2 catheters (reference catheter in the Coronary Sinus (CS) & mapping catheter in the Left Atrium) was performed with the ESN during MR imaging (Fig. 6), demonstrating <6mm positional error of the CS catheter relative to its position outside MRI, and <5% IQ Reduction in both SE & GRE. Electrode temperature rise was observed to be <1°C with 4 Watt/kg SAR sequences and no surface burns. TR elongation was required in TR<4ms sequences to retain a sufficient window for ESN operation.

Conclusions: Continuous catheter tracking during MR imaging was demonstrated with the MRI-compatible ESN system, permitting registration-free EAM inside and outside MRI during EP procedures, and no MRI IQ compromises.

Fig.4: MRI-compatible catheters (a) non-irrigated catheters with 5 MR-tracked and 2 ESN electrodes, (b) irrigated catheter with 8 ESN electrodes.

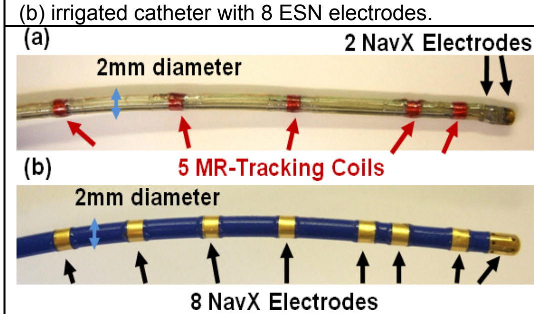


Fig.5: Simultaneous ESN and MR tracking in a Left atrial phantom using a dual MR- & ESN-tracked catheter.

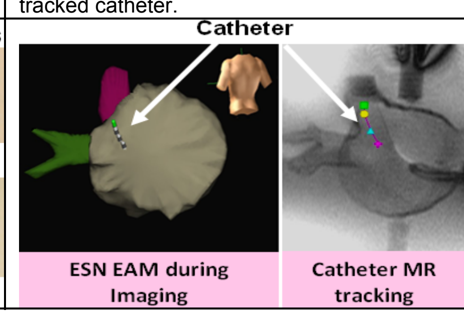


Fig.6: ESN-based EAM during swine MRI imaging. Reference catheter in Coronary Sinus and mapping catheter in Left Atrium.

References: [1]Dukkipati, Circulation'08. [2]Schmidt, Circulation A&E'09. [3]Nademanee, JACC '04. [4]Early, Eur.Heart J'06. [5]Tse, ISMRM'11.