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MR guided cardiac ablation: how to build an interventional magnetic resonance suite and what's the role of the imaging

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Magnetic resonance (MR) represents a new interesting imaging approach for guiding electrophysiology (EP)-based ablation procedures of atrial flutter and typical atrial fibrillation. This new approach permits to reach good results if compared with conventional EP ablation. Tissue characterization by MR permits to detect cardiac anatomy and pathological substrate like myocardial scars well visualized with late gadolinium enhancement (LGE) sequences. Intra-procedural imaging is useful to real-time follow the catheter during the ablation procedure and at the same time to visualize cardiac anatomy in addition to understanding if the ablation is correctly performed using oedema sequences. Performing cardiac ablations inside an MR room permits to reduce radiation exposure and occupational illnesses.

General consideration

Current guidelines[1-3] suggest that catheter ablation of cardiac arrhythmias is a well-established therapy for the majority of supraventricular and ventricular tachycardias. MR offers a wild range of advantages as a guide in many fileds of Interventional Radiology, in particular, new interesting perspective are investing Interventional Cardiologist procedures. For both oncological and cardiologist procedures it requires some technical characteristics that must be provided before installation to be able to link the diagnostic capability of MRI with its promising role in interventional procedures.

How to build an MRI interventional room

Proper planning before interventional magnetic resonance (IMR) installation is mandatory to obtain a room equivalent to an operating theater in terms of sterility, patient care in case of emergency and spatial capacity.[4]

Room dimensions: considering that a perimeter around the scanner is necessary to allow both the operator movement and the positioning of monitors and machineries for cardiac and oncological ablative procedures, a rectangular room with dimensions at least of 30 m^2 must be planned, considering a resonance foot-print at least 5,5 m^2 (*Figure 1*).

Safety: access room doors must be positioned to allow rapid access in case of emergency; the access to the patient must not be hindered by cables, monitors, or other equipment. To have easy accessibility, oxygen hooks and all the anaesthetic management equipment have to be placed laterally to the patient, at least 1 meter from the side of the magnet. An anaesthetic assistance system with medical gas and a non-magnetic 12-lead monitor are positioned inside the room. MRI safe defibrillator are still not available but must be provided outside the room. Near MRI department is present an angiography room useful in case of emergency to implant a temporary pacemaker.

Devices: it is important to have space all around the scanner to arrange monitors for the real-time MR images visualization during the ablative procedure, MR-compatible RF technology and cables, anaesthetic MR-compatible

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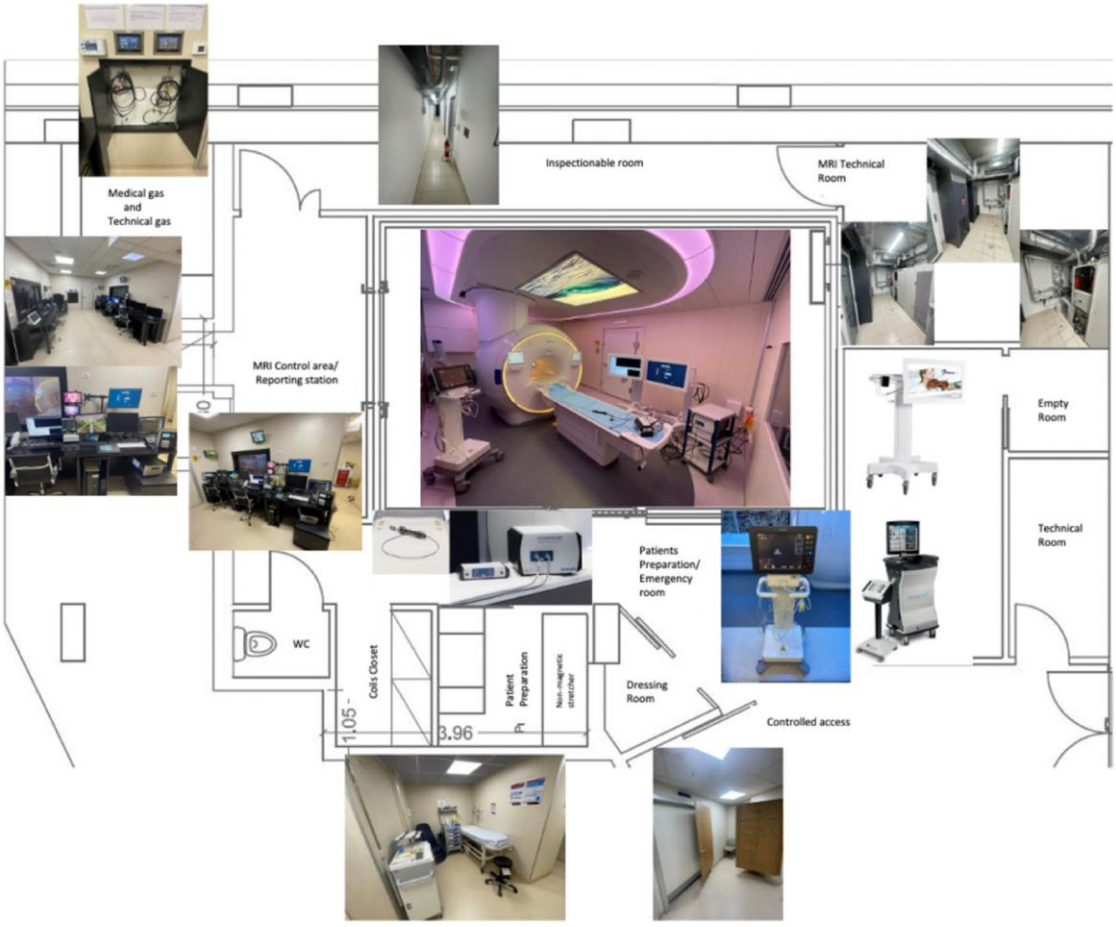

Figure 1 Map of the interventional MR department of policlinico casilino of Rome, Italy. At the centre of the picture, the scanner room. All around are present several technical rooms and the MRI cardiac ablation devices needed for the procedure.

management assistant machines for patient sedation. Non-magnetic pericardiocentesis needles are available inside the room in case of ablation procedures complications.

Operating theater like room: air/minute exchanges identical to those used in operating rooms and filtration systems must be provided planning a ventilation system useful to meet both the safety requirements for the specific magnetic resonance regulations and to guarantee a suitable level of sterility. Moreover the system must guarantee a positive pressure from the interventional environment to the surrounding areas.

MR-guided cardiac ablation equipement

MR room architectural structure must be linked with software equipment. Cardiac ablation MR-compatible devices such as the Vision-MR Ablation Catheter and Advantage-MR (AMR) Electrophysiology (EP) Recorder/Stimulator system put together to a new catheter form are technologies that allow this kind of procedure in the the Interventional MRI suite ('iSuite').[5]

Inside the scanner room

The system consists of an in-room control navigation software communicating by ethernet connection to many applications to integrate data such as voltages, pH or blood pressure. It is standalone and has a low-latency real-time connection with the scanner.

An open-irrigated RF ablation catheter is used; it is characterized by the presence of gold electrodes and fibre optic tip temperature sensing. MR tracking is possible because of the presence of two MR receive coils. The AMR system permit to have EP recorder and cardiac stimulator in one system.

Two monitors to visualize MRI images and ECG signals are arranged in the scanner room, in front of the operator.

Outside the scanner room

Elimination of arrhythmias is possible by radiofrequency (RF) generation. RF generator is connected to the Vision-MRAblation Catheter via the Advantage-MRI system and it is positioned outside the scanner room; the connection with the catheters inside the room is possible due to cables passing in some small holes in the scanner room wall. Moreover a monitor to visualize surface and intracavitary ECG has to be positioned both outside and inside the scanner room, one more monitor for vital signs and for pulse oximetry monitoring and a radiofrequency ablation setting dispositive is needed. Intracardiac electrograms

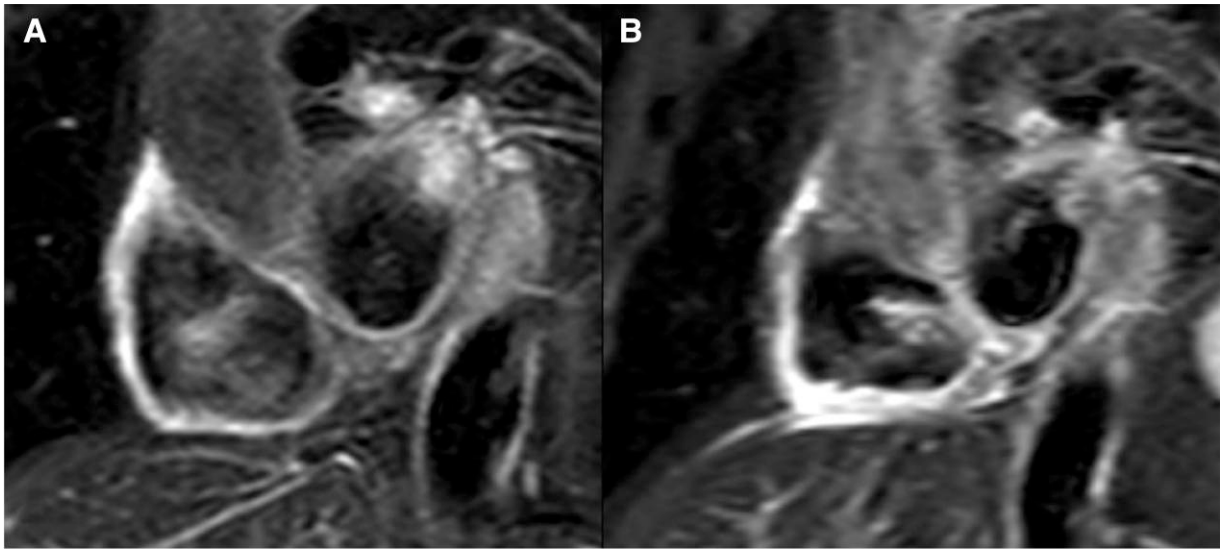

Figure 2 (*A*) Pre-ablation black blood T2 STIR sequence oriented along the short-axis bi-atrial plane show normal aspect right atrial wall. (*B*) Post-ablation sequences show the presence of intramural oedema as a sign of tissue reaction to ablation treatment (arrow).

and surface ECG signals provide for the localization of the cardiac arrhythmia.

MR cardiac ablation imaging

The possibility to visualize at the same time high resolution cardiac anatomy and ablation catheter without ionizing radiation exposure represent a new interesting therapeutic approach for supraventricular and ventricular tachycardia. Moreover this new technique, due to the possibility to visualize the arrhythmia substrate, can be considered the starting point that opens the doors of new interesting approaches for ventricular tachycardia ablation therapies. MR imaging is useful in all the phases of the ablation procedure:

Pre-procedural imaging

In our knowledge not clear indications are reported in the literature about pre-procedural imaging for MR-guided flutter or atrial fibrillation ablation. Could be considered an ECG-gated, steady-state free precession (SSFP) breath-hold sequences (echo time, 1.63 ms; repetition time 3,3 ms; slice thickness 8 mm; field of view, AP 187 × RL 112 mm; and pixel size, 1.6 × 1,6 mm; gap 0 mm; 2 slices for each breath-hold) oriented in short-axis bi-atrial and two chamber (2ch) right para-atrio-ventricular plane for anatomic cavo-tricuspid isthmus (CTI) characterization in terms of length and detection of potential concave variants. SSFP short-axis and long-axis four chamber (4ch) planes can be acquired for a global anatomical study of the heart and to obtain right ventricle (RV) and left ventricle (LV) functional parameters. Short-tau inversion recovery sequence (STIR) in the right atrio-ventricular 2ch long-axis and 2ch bi-atrial plane can be considered. An electrocardiography triggered and respiratory navigator gated 3D-gradient echo pulse sequence can be considered for better anatomical evaluation of the heart.[6] Phase-sensitive inversion recovery or 3D-TFE T1-weighted sequences for detection of atrial fibrosis.

Intra-procedural imaging

Ablation system equipment connects directly to 1.5 T MRI scanners allowing for active catheter tracking (ACT) and active catheter imaging (ACI) during the ablation procedure. AMR provides real-time imaging guidance of the Vision-MR Catheters during cardiac ablation procedures in the MR room. This technique is called ACI. Two integrated MR receive coils reside in the tip of the Vision-MR Catheter (distal coil is 8 mm from catheter tip). MR fields interact with these coils to provide real-time guidance and confirmation of location. The RF energy absorbed by the coils is seen on-screen, real-time, and is depicted as two bright circles when in the scan plane. The passive tracking technique is a consolidated imaging technique that doesn't require any special software and permits to visualize the susceptibility artifacts or signal void of the catheter and guidewires.[7, 8] T2-weighted short-tau inversion recovery sequence (STIR) oriented in 2ch right para-atrio-ventricular plane for the detection of CTI oedema can be acquired immediately after the ablation procedure. The presence of reactive oedema is the sign of the phlogistic reaction to the ablation therapy, and it is a good intra-procedural marker to detect the ablation procedure extension (*Figure 2*).

Post-procedural imaging

At the end of the procedure SSFP cine sequences to evaluate right atrial wall motion, the presence of intracavitary thrombi and ventricular function can be performed. LGE sequences are useful for detecting areas of altered washout gadolinium timing due to ablation damage and fibrosis extension differences between pre and post-ablation procedure at long follow-up. STIR sequences can be useful for evaluation of oedema regression if performed immediately after the ablation and at long follow-up.

iCMR—interventional MRI suite

This system is very useful during ablation procedures because of the presence of many tools such as MR fluoroscopy visualization, 3D auto-segmented roadmaps, bookmark targets for planning access, easy switching between sequence geometry. Operator can visualize real-time the catheter tip and heart anatomy, unlike to traditional EP procedures where the electro-anatomical maps are generated by a software; if the the breath gating is not good or if the patient moves during the procedure the map conformity with heart anatomy can lack in precision. Moreover, it is not always possible to obtain EP maps of all the regions of interest, whereas MRI guidance permits visualizing anatomy and to perform tissue characterization of the whole heart anatomy, also with 3D cardiac anatomy software.

Occupational benefits

Most important workplace concern for interventional physicians and cath lab staff is their daily exposure to ionizing radiation from the angiographic X-ray systems that are central to their procedures. In addition to increased cancer risks and developing cataracts, they are also worried about orthopaedic issues caused by wearing heavy radiation protection aprons, which takes a toll on the spine and can lead to chronic back problems. Among occupationally exposed healthcare workers, interventional physicians are among the most highly exposed, and there is potential for exposure to support personnel as well.[9]

Perspective directions

Actually CMR-guided ablation of the cavo-tricuspid isthmus for typical atrial flutter is an increasing technique in alternative of conventional X-ray procedures. The possibility to have a 3D visualization of the heart, the real-time relationship between the tip of the ablation catheter and the heart anatomy, permits to be confident with the area to treat. Furthermore, thermic maps associated with oedema sequences can give intra-procedural information about the localization and extension of the ablation area. Considering the strength of cardiac MRI to visualize myocardial scar, in particular in the left ventricle, ablation of ventricular arrhythmias represent the more important future perspective of this technique that nowadays has to be considered the starting point for great new future directions. Research in CMR-guided EP requires a broad team including physicists, engineers, radiologists, electrophysiologists, and computer scientists. The cost associated with installing expensive IMR suites, does also limit the widespread application of interventional CMR.[10] A possibility to amortise the costs of the installations of an IMR can be to share the scanner between radiologist and interventional physician alternating diagnostic session to interventional sessions (cardiology and/or oncology sessions). It is necessary that these two figures be in good relations with each other to cooperate to optimize protocols, for research and to make cost-effectiveness an IMR suite.

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Data availability

No new data were generated or analysed in support of this research.

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